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Publication Office: 20th and Northampton Sts., Easton, Pa.

Editorial Office: 845 S. Wabash Ave., Chicago, Ill.

Subscription Price:

Members of Local Sewage Works Associations affiliated with the Federation, $1.00 per year.

Non-members: Total fee $3.00, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50 per year; other countries, $4.00 per year.

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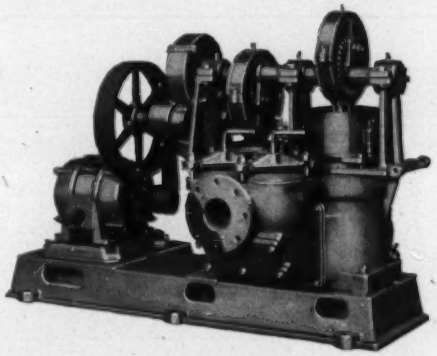

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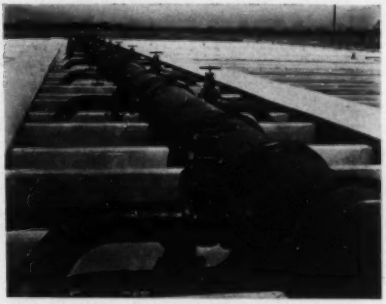

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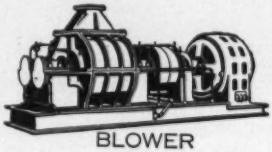

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Vol. III **April, 1931** **No. 2**

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Sewage Research

The Removal of Biochemical Oxygen Demand by the Trickling Filters at Decatur, Illinois

By William D. Hatfield*

In a study of trickling filter loadings and efficiencies we must first define the terms and establish the laboratory tests on which we are to base calculations of efficiencies. The definition of terms is necessary so that misunderstandings will not arise. A good trickling filter effluent should be low in biochemical oxygen demand and should have at least a few parts per million of nitrates. The amount of nitrates present will depend to a large extent on the amount of nitrogen in the applied sewage and also on the filter loading, for after the loading has reached its maximum there is a decrease in nitrates. Suspended matter has not been considered in this discussion because it should be removed by final sedimentation, and therefore does not detract from the true quality of the effluent, except perhaps during occasional periods of sloughing.

The purpose of the trickling filter is to remove as much as possible of the dissolved and colloidal organic matter and to stabilize the remaining solids by processes of absorption and oxidation. The efficiency of a filter is a measure of this removal and at present is best indicated by the removal of biochemical demand. Therefore in this paper the efficiency of trickling filters is defined as the percentage removal of B. O. D. This percentage removal may or may not be related to nitrate formation or the stability of the effluent. By this definition, efficiency is not related to the quality of effluent but is the percentage removal of B. O. D.

The quality of the final effluent depends, among other things, on the residual B. O. D. therein, but the actual work accomplished by the filter is better represented by the percentage removal of the inflowing organic load. It is this filter-work that is being discussed in this paper.

The stability toward methylene blue of an effluent is primarily dependent on the nitrates present. For example, a good effluent with only 5 parts per million of B. O. D. may have a 5-day stability because of only 1 p. p. m. nitrate, while a poor effluent with 50 p. p. m. B. O. D. may have a stability of greater than 10 days (90% +) because of 20 p. p. m. nitrates. (The latter effluent was actually obtained at Decatur with a very strong sewage.) Nitrates and stability are good indices of the condition and operation of an individual filter, but are poor indices of the quality of the effluent when

* *Supt. of the Sanitary District of Decatur.*

not correlated with the biochemical oxygen demand. They are of little value in comparing the relative efficiencies of different plants. (See *U. S. Pub. Health Service Bull.* 132, pages 18–19.) Their value as a routine method to assist in plant operation is not questioned.

The term "filter loading" should include both the rate of application of the influent, in million gallons per acre per day, and the concentration of organic matter applied (p. p. m. B. O. D.). Greeley and Hatfield[3] have expressed this loading in pounds per acre per day of B. O. D., applied as follows: Loading = lbs. per acre per day = p. p. m. influent B. O. D. × 8.34 × million gallons per acre per day.

It is more logical to express loading by surface rates, rather than to divide the loading by the depth of the filter, which gives the data on an acre-foot basis. The acre-foot loading assumes that the last foot of filter depth does exactly the same percentage work as the first or top foot. This is not true, particularly with the removal of B. O. D., which takes place largely in the upper portions of the filter. The removal of B. O. D. is a logarithmic function and not a straight-line function. Until the varying rates of oxidation in each foot of depth of the filters are known accurately, and these varying rates applied mathematically to the surface loading, we cannot logically use the "per acre foot" loading.

From the data in the literature and presented later it appears that the relation between trickling filter loadings and efficiencies of B. O. D. removal may be proportional, but that the relation between loading and quality of effluent is dependent on many factors and is a complicated problem not yet solved. The maximum loading limit which a filter may take under a given set of conditions and produce a satisfactory effluent is of considerable importance to the designing engineer.

Keefer[5] presented data on the Baltimore filters which indicated that the percentage removals of B. O. D. were greater with increased strength of sewage. Childs and Schroepfer (private communication) have collected data from 15 widely separated plants which apparently indicate that the percentage removal of B. O. D. for any given sewage is not materially affected by rather wide variations in the strength of the applied sewage or by the rate of application. There were rather wide variations, however, between the percentage removals of the individual plants. It is also interesting in this connection that Hatfield[4] found that the percentage removal of B. O. D. by pre-aeration of the strong starch-waste sewage of Decatur depended on the time, expressed in hours of aeration, and not on the strength of the sewage (within the limits of 300 to 1000 p. p. m. B. O. D.).

If normal variations in sewage strength and rate of application have only a slight effect on the efficiency of a trickling filter, what then are the factors which cause the wide variations in efficiencies of various plants? The Decatur sewage treatment plant has operated with a wide range of sew-

age concentrations, rates of application and efficiencies. In the early days (1925–1926) the existing Imhoff tank-trickling filter plant was greatly overloaded with a starch-waste sewage mixture having a population equivalent of from 300,000 to 400,000. Then followed the experimental pre-aeration of this mixture to increase the capacity or loading of the existing filters. This was followed by the construction of the pre-aeration plant proper and the simultaneous recovery by the industry of a very large part of the plant sewage losses. The present plant, including the pre-aeration unit, has a designed capacity of 150,000 population equivalent. This capacity was reached in 1928 by the reductions mentioned and in 1929 the sewage was further reduced to between 100,000 and 120,000 population equivalent. In 1930, due to more efficient recovery of the starch wastes and also to a reduced operation during the business depression, the population equivalent has been about 80,000. Operation of the filters during these periods furnishes data which are most interesting from the standpoint of filter loadings and efficiencies.

For the sake of clarity let us classify the variable factors which may enter into or affect filter efficiencies in two groups, as follows:

1. Structural variables (design).
   - Depth of filter
   - Type of underdrains and ventilation
   - Length of dosing and rest periods
   - Size, shape and kind of filtering material.
2. Physiological variables.
   - Quantity of food for growth and its concentration
   - Quality of food, or kind of organic matter
   - Concentration and quality of air (see ventilation and underdrains)
   - Temperature for growth
   - Toxic chemicals in sewage.

In comparing efficiencies of different filters it is exceedingly difficult to get all the necessary data on each variable. Therefore let us try to eliminate a few of the structural variables by a study of the literature and then make the other structural variables constant by limiting our study to the Decatur plant.

Structural Variables

Depth of Filter. Depth is probably not an important factor after a depth of six feet is reached, except for certain unusual sewages or trade wastes. Buswell and Strickhouser[2] have summarized their studies on the 10-ft. filters at Urbana-Champaign somewhat as follows:

1. The quality of effluent from the 10 ft. level was no better than that from the 6 ft. level. 2. The additional depth below 6 ft. did not produce a more satisfactory effluent at higher rates of filtration.

Moreover, ponding and clogging became the limiting factors for high rates of filtration. 3. A larger area of 6-foot filters at lower rates will produce more purification than an equal cubical volume of 10-foot at proportionally higher rates, because the first 6 feet do most of the work.

Levine[6] has published data on the treatment of skim milk wastes on an experimental filter 6 ft. deep, from which the following quotations are taken:

1. The elimination of solids took place primarily in the upper 3 feet of the filter. Suspended solids were developed in the second to fourth foot of the filter.

2. The oxygen-consumed values (30 minutes boiling with permanganate) for the raw wastes were 195, 375 and 716 p. p. m. . . . . The reduction in oxygen-consuming constituents was 75.1 to 87.3 per cent . . . . As was observed with the solids, the elimination of oxygen-consuming constituents was almost entirely in the upper 3 feet of the filter.

3. With higher rates of application a greater depth of filter was concerned with the removal of organic nitrogen constituents.

4. Ammonification was most marked in the upper layers of the filter.

5. Nitrates were reduced in the first foot but increased gradually thereafter.

6. Stability of the effluent is intimately associated with the nitrate content.

Although the data in the literature on the work accomplished in a sprinkling filter are somewhat discordant, nevertheless it is pretty well established that the oxygen-consuming organic matter is largely removed in the first three or four feet and that the nitrogen is lost as ammonia, or is oxidized to nitrates, more gradually as the depth increases toward six, eight or ten feet, depending on the concentration of nitrogen present. The upper portion of the filter may be considered as somewhat similar to the first stage or carbonaceous oxidation stage of the B. O. D. curve and the lower portion of the filter as the nitrifying or secondary stage of the B. O. D. curve. Filters with greater depths than six feet may produce higher nitrates with very strong sewages or trade wastes, but with normal sewages it is doubtful if greater than six-foot depths are economically advisable.

Type of Underdrains and Ventilation.—The underdrains should be designed with sufficient capacity to carry away the filtered sewage as it arrives on the filter floor. Certain experiences at Decatur would indicate that even this is not absolutely necessary, although it is of course advisable. The filters at Decatur operate by gravity and at certain stages of the river have operated with one or two feet of the stone submerged for periods of two to three weeks without any considerable deterioration of the effluent.

In fact, they have operated fairly well with three feet of the stone submerged.

Buswell and Elder[1] reported, from data on the composition of air in filters, that no significant depletion of oxygen was noted even in the bottom layers of a filter constructed with underdrains which were inadequate to drain the water properly.

The above data are not an argument for poor underdrain design, but an attempt to show that the underdrain and ventilation systems probably are not a vital factor in the efficiency of the average filter, at least among those studied, and may reasonably be eliminated as an unimportant variable, so far as the efficiency of oxygen-demand removal is concerned.

Length of Dosing and Rest Periods.—During the past five years the Decatur sewage has been dosed over a wide range of dosing cycles without showing much effect on the final effluent. The old dosing tanks operated on a cycle of 8 to 12 minutes. The testing station filter was operated on cycles as low as 3 minutes, without any apparent change in the effluent. The new dosing tanks operate on an 18- to 20-minute cycle, with 8 minutes to spray. Since good results have been obtained with such wide variations in sewage strengths, using dosing cycles from 3 to 20 minutes, it appears that satisfactory results may be obtained on almost any reasonable cycle, and that this variable may be neglected in comparing results. The author's experience with very long cycles, *i. e.*, one to two hours, indicates a lowered efficiency in these extreme cases.

Size, Shape and Kind of Filtering Materials.—The committee[7] of the American Society of Civil Engineers on filtering materials for sewage and water filters have compiled some very useful data on filter materials and it is hoped they will extend the work from the structural and physical point of view to that of size and efficiency of filter operation. In studying the Decatur data this variable may be neglected because all the data are on the same filtering material.

Physiological Variables

A study of the Decatur filters will be of particular interest since the structural variables mentioned above are either immaterial or constant and because of the wide range of the physiological variables during the past few years. The B. O. D. has varied both in quantity and quality and the average monthly sewage temperatures have ranged from 65 to 95 degrees Fahrenheit.

Data on the influent and effluent B. O. D., the per cent removal of B. O. D., nitrates and stability of the effluent, and the temperature of the sewage during 1925, 1926, 1928, 1929 and 1930 are given in Tables I, II and III. Table I contains average monthly data for the 3-acre sprinkling filter before the starch wastes were largely recovered by the starch industry.

Table II contains the average data for the testing station. The testing station was operated during the same years as are represented by the data in Table I and was treating the same sewage, except that it was modified by pre-aeration. Table III contains the average data for the same three acres

TABLE I

MAIN FILTER LOADINGS AND EFFICIENCIES, 1925–1926

Date		Mil. Gal. per Acre per Day	Biochemical Oxygen Demand Influent, P. p. m.	Loading, Lbs./Acre/-Day	Effluent P. p. m.	Per cent Removal B. O. D.	Temp., ° F.	Nitrate N, P. p. m.	Stability, Per cent
1925	May	1.70	371	5250	25	93	91	11.3	90
	June	1.76	388	5700	24	94	93	7.2	90
	July	2.00	290	4830	26	91	92.5	4.3	90
	Aug.	1.50	344	4300	32	91	94.5	7.4	90
	Sept.	1.28	405	4320	25	94	93	9.2	90
	Oct.	1.21	530	5340	79	85	83	5.5	60
	Nov.	0.74	610	3760	130	79	78	6.5	40
	Dec.	0.79	595	3920	71	88	77	17.0	60
1926	Jan.	1.06	650	5740	63	90	74	20.0	90
Average		1.34	465	5200	53	89.5	86	9.8	78

TABLE II

TESTING STATION FILTER LOADINGS AND EFFICIENCIES, 1925–1926

Date		Mil. Gal. per Acre per Day	Biochemical Oxygen Demand Influent, P. p. m.	Loading, Lbs./Acre/-Day	Effluent, P. p. m.	Per cent Removal, B. O. D.	Temp., ° F. Crude Sewage	Nitrate N, P. p. m.	Stability, Per cent
1925	Sept.	3.50	146	4250	31	79	93	5.9	54
	Sept.	3.78	195	6150	44	78	93	11.0	85
	Oct.	3.50	237	6900	38	84	83	7.6	79
	Oct.	3.36	269	7550	52	81	83	8.6	90
	Nov.	3.36	387	10800	67	83	78	6.6	54
	Dec.	1.74	317	4620	69	78	77	14.0	89
	Dec.	2.54	430	9030	72	83	77	3.3	33
1926	Jan.	2.52	425	8920	103	76	75	3.3	11
	Jan.	2.37	340	6720	58	83	82	12.0	87
	Feb.	3.00	284	7100	54	81	80	10.6	77
	Feb.	3.0–5.0	118	2950–4910	41	65	70	18–13	99
	Mar.	4.28	110	3920	39	65	70	19.6	99
	Apr.	3.30	46	1260	16	65	60	18.0	99
Average		3.18	254	6730	53	77	79	10.6	74

NOTE: The second part of the table consists of high rates of application of an effluent produced by from 7 to 11 hours pre-aeration thus approaching activated sludge treatment (see Greeley and Hatfield[3]).

of filters as those represented in Table I, but the influent has been treated in the pre-aeration plant that was constructed in 1927.

Quantity of Food.—If one compares the strength of influent sewage with the filter efficiencies in these tables it is quite apparent that the high efficiencies were obtained with influents of high B. O. D. In Table I the

B. O. D. varies from 371 to 650 p. p. m. and the efficiencies average 89.5 per cent. In the first section of Table II the B. O. D. varies from 146 to 425 p. p. m. and the average efficiency is 80.6 per cent; in the last section of the same table, due to prolonged pre-aeration, the B. O. D. varies from 46 to 118 p. p. m. and the efficiency is reduced to 65 per cent. The average efficiency for the testing station filter given in Table II is 77 per cent.

TABLE III

MAIN FILTER LOADINGS AND EFFICIENCIES AFTER PRE-AERATION, 1928–1929

Date	Mil. Gal. per Acre per Day	Biochemical Oxygen Demand Influent, P. p. m.	Loading, Lbs./Acre/-Day	Effluent, P. p. m.	Per cent Removal, B. O. D.	Temp., ° F.	Nitrate N, P. p. m.	Stability, Per cent
1928 May	3.33	118	3270	41	65	77.5	4.0	77
June	3.04	>130	>3300	38	>71	76.0	5.5	84
July	3.44	95	2720	19	80	84.5	5.5	98
Aug.	3.29	100	2740	23	77	89.5	6.3	98
Sept.	3.80	98	3090	17	83	89.5	5.6	98
Oct.	3.25	117	3160	17	86	86.5	2.5	95
Nov.	3.23	233	6270	48	79	80.5	2.4	57
Dec.	3.23	176	4730	38	78	69.5	4.0	50
1929 Jan.	3.73	150	4680	55	63	67.0	6.0	25
1929 Feb.	3.60	230	6100	71	65	69.0	2.3	7
1929 June	2.92	47	1140	16	66	74.0	1.9	79
July	3.30	77	2120	20	74	75.0	2.1	73
Aug.	3.23	105	2820	18	83	88.0	2.6	95
Sept.	3.11	113	2930	14	88	87.0	3.9	83
Oct.	3.31	93	2560	17	82	83.0	3.0	85
Nov.	3.06	108	2750	23	79	78.0	3.0	65
Dec.	3.32	106	2930	30	72	68.5	2.1	58
Average 1928–1929	3.30	122	3250	30	76	79.0	3.7	72
1930 May	3.94	72	2380	27	63	77	2.2	89
June	3.47	67	1940	20	70	83	4.7	97
July	3.18	58	1540	11	81	94	4.4	98
Aug.	3.15	64	1680	11	83	94	4.7	99
Sept.	3.20	65	1740	12	82	90	4.1	99
Oct.	3.21	80	2140	17	79	82	2.4	68
Nov.	2.63	74	1620	18	76	78	7.3	95
Dec.	2.46	100	2050	34	66	71	3.7	80
Average 1930	3.16	73	1890	19	75	84	4.2	91

The average data in Table III for 1928 and 1929 check closely with those in Table II, since the average influent B. O. D. was 122 p. p. m. and the filter efficiency was 76 per cent. The average data for 1930, also given in Table III, show a further decrease in influent B. O. D. without a further decrease in efficiency. However, during this year the sewage temperatures were somewhat higher and this would have increased the efficiencies. The effect of temperature on efficiencies is discussed later in this paper.

The average filter effluents shown in Tables I and II are similar with a rather high B. O. D. (53 p. p. m.) and about 10 p. p. m. nitrates. These results were obtained with the filters operating most of the time at, near or above their maximum loading. The average filter effluents shown in Table III are much better than those above with a B. O. D. of 30 and 19 p. p. m. and nitrates of about 4 p. p. m. Thus, with a greatly decreased load, and a decreased removal efficiency, the final effluent is much improved.

Quality of Food.—Pre-aeration, as practiced at Decatur, reduces the B. O. D. of the Imhoff effluent from 25 to 50 per cent. This reduction of B. O. D. is accompanied by practically no reduction in total or organic nitrogen, thus indicating that it must be the easily oxidizable carbonaceous

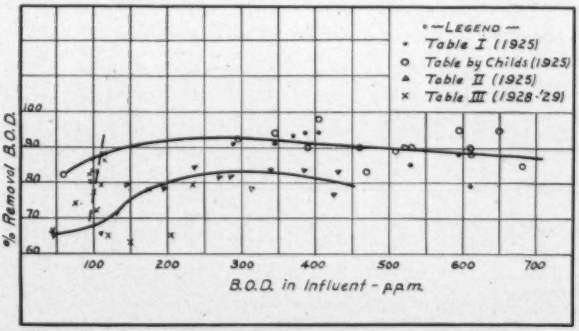

FIG. 1.—Percentage Reduction of B. O. D. Based on Influent, Decatur Trickling Filters.

organic matter that is removed by the short aeration period. The removal of this easily oxidizable material reduces the burden on the potential oxidizing powers of the filter bed, thereby allowing an increase in the rate and load that can be applied to the filters. But this load consists of the more resistant organic matter remaining in the pre-aeration effluent, and therefore a reduction in the efficiency of the filter is not surprising. The differences in efficiency of the main filter and the testing station filter are easily seen in Figure 1. These differences would apparently support the contention that a change in the quality or kind of organic matter present changes the filter efficiency, were it not for the discordant data plotted as crosses, which represent the data in Table III for the main filter in 1928 and 1929. The latter data are based on an influent B. O. D. of approximately 100 p. p. m., but the efficiency varies between 65 and 90 per cent. These results therefore throw a considerable shadow of doubt on the effect of the

quantity or quality of organic food supply on the filter efficiency, at least in this particular case.

Temperature of Sewage.—Temperature is another variable that is recognized as affecting the quality of a filter effluent. Winter temperatures almost always reduce the nitrate formation and the stability of an effluent. The data in the tables and in Figure 2 show a decided correlation between the average temperature of the sewage and the per cent removal of B. O. D. by the filters. In fact, except for the three months, December, 1925, January, 1926, and August, 1928, the correlation for the other 23 months is exceptionally close. No explanation for the three exceptions has been found in any related data.

During 1925 and 1926, when the temperature was above 90 degrees, the

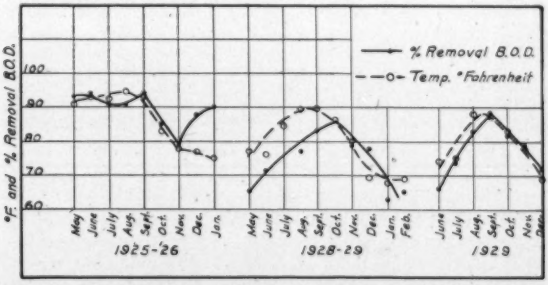

FIG. 2.—Correlation of Percentage B. O. D. Removal and Temperature, Decatur Trickling Filters.

efficiency was above 90 per cent; when the temperature was 83 degrees the efficiency dropped to 85 per cent; when the temperature was 78 degrees the efficiency had dropped to 79 per cent.

During 1928 and 1929, and with pre-aeration effluent, the summer sewage temperatures were between 80° and 88° F. and the filter efficiency was between 80 and 88 per cent. These data check almost exactly with the same temperature conditions and efficiencies in October and November, 1925, when the filters were receiving a very much stronger sewage. With sewage temperatures between 60° and 70° F. the efficiencies were between 60 and 70 per cent. The average sewage temperature for 1928 and 1929 (Table III) was 79 degrees and the average filter efficiency was 76 per cent. The sewage temperatures and efficiencies in 1930 (Table III) show the same parallelism; the average temperature was 84° F. and 75 per cent removal of B. O. D. was obtained. This is a somewhat lower removal than we have had previously at a temperature of 84 degrees.

This lower efficiency is probably due to a much lower loading of the filters during 1930. The data in Tables I, II and III, and Figures 1 and 2 show that temperature is more closely correlated with filter efficiency than the other variables studied at Decatur.

Filter Loadings.—The plant loadings shown in the tables are expressed in pounds of B. O. D. (5-day B. O. D. at 20° C.) applied per acre per day. During 1925 and 1926 the filters were pushed to their capacity in an attempt to purify as much of the strong sewage-waste mixture as possible. In October, 1925, the filter was overloaded with exceptionally strong sewage, causing a deterioration in the filter efficiency which was not overcome until in January, 1926. This serious overloading occurred on four consecutive days, during which loads of 10,000 pounds B. O. D. per acre per day were applied. Taking individual days and monthly averages into consideration, it seems that the filter could handle average loads of 5000 pounds B. O. D. per acre per day, provided excessive loads above that average figure were not applied.

During the same years with pre-aeration effluent (Table III), loadings of 7500 pounds B. O. D. per acre per day were handled with an efficiency of 80 per cent removal, nitrates of 6 to 10 p. p. m. and stability about 80 per cent. These data show an increased loading of the test filter of about 50 per cent and an increased rate of application from about 1.3 to 3.5 million gallons per acre per day, due to pre-aeration of the influent.

The loadings on the main plant filter shown in Table III are hardly comparable with the earlier loadings because of the large reduction in sewage strength, due to the recoveries made by the starch manufacturing company in the early part of 1928. The average filter loading for the two years 1928 and 1929 was 3250 pounds B. O. D. per acre per day, and that for 1930 was less than 2000 pounds per day. The average removal of B. O. D. during both these periods was very near 75 per cent. This percentage removal is not far from the average in Table II, although it is intermediate between the data in the first and second parts of the table.

Quality of Effluent.—The quality of effluent from the filters has become better with each reduction in the filter load, even though the percentage removal of B. O. D. has been reduced. An increase in filter load may slightly increase the efficiency of B. O. D. removal but it will more greatly increase the B. O. D. in the effluent. It may also increase the nitrates so that the stability will remain as high as before.

It does not seem possible to state a maximum filter loading at Decatur unless a definite quality of effluent is stipulated. In 1925, with the crude sewage B. O. D. running between 600 and 1000 p. p. m., we were entirely satisfied with 90 per cent stable effluents even though the average B. O. D. may have been above 50 p. p. m. part of the time. At that time stability to methylene blue seemed to be satisfactory, for we were glad to get even

those results. But during the drought of 1930 it has been still more satisfying to have an effluent during the summer months with a B. O. D. of 11 p. p. m. and a stability of 99 per cent. The Sangamon River below Decatur, which during the last six months of 1930 has consisted almost entirely of the above effluent, has been a clear, pretty stream with a good positive oxygen balance, a clean sand and stone bottom, and has contained more than its share of fish life.

Conclusions

It is with hesitancy that I draw conclusions on this rather complicated subject. It seems possible to state that (1) at Decatur the percentage removal of B. O. D. by the filters is more closely correlated with the temperature of the sewage than with any other known factor, and (2) the maximum permissible loading of filters must be based on the maximum allowable B. O. D. in the final effluent. Filter loadings have varied from 2000 to 10,000 lbs. per acre per day of 5-day B. O. D. Under the conditions of 1925 and 1926 the maximum load appeared to be about 5000 lbs. per acre per day. With pre-aeration this load could be increased to 7500 lbs. per day and an effluent could be obtained with sufficient nitrate to give fair stability. In 1930 with pre-aeration loadings of only 2000 lbs. per acre per day excellent effluents with very low B. O. D. and 99% stability were obtained.

Notes: The data presented in the tables were obtained as follows:

Mil. Gal. per Acre per Day.—In Table I the rates are estimated from frequent timing of the dosing cycle, but in Tables II and III are calculated from metered volumes and are accurate.

Biochemical Oxygen Demand.—B. O. D. was determiend according to the Standard Methods of the A. P. H. A. and is expressed as 5-day demands at 20° C.

Nitrates were determined by the reduction method and include the nitrites.

Stability toward methylene blue was at 20° C. and according to Standard Methods of A. P. H. A.

Temperatures in all cases are the temperatures of the crude sewage. There is very little loss of temperature as the sewage passes through the Imhoff and aeration tanks. The temperatures in Tables I and III are therefore very near to those of the applied sewage. Those in Table II are not so accurate because the Simplex type of aeration in the testing station tended to lower the temperature during cold winter weather. A temperature record was not kept of the testing station filter influent.

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Report of the Water Pollution Research Board for the Year Ended June 30, 1930. *Dept. of Scientific and Industrial Research.* Director, Dr. H. T. Calvert. This is the third annual report of the work of this British research board. The monthly summaries of current literature dealing with water supplies, sewage, trade-wastes waters and river pollution are the most valuable abstracts in this field, and should have wider circulation in America. They may be obtained from H. M. Stationery Office, Adastral House, Kingsway, London, W. C. 2. The subscription rate is $3.65 per year.

The work of the Board during the year covered by the report has included a survey of the River Tees which included monthly observations and sampling at 16 stations in the upper non-tidal section of the river and also series of observations throughout the 24 hours to ascertain the changes which occur during the day and night. Very complete analyses have also been made in the lower or tidal reaches, to determine the effect of the tide. Biological examinations have been made in great detail.

Investigations of the treatment of beet-sugar wastes have been continued. The use of $^1/_8$- to $^1/_4$-inch clinker was found to be inadvisable, but $^3/_8$- to $^5/_8$-inch media were used successfully for 88 days of the 1929–30 campaign, treating pulp press liquor, diluted with 3 to 4 volumes of river water, at the rate of 120 gallons per cubic yard per day. The biology of the filter films is being studied at the Rothamsted station.

Fundamental studies of biological aspects of the activated-sludge process are being made at the London School of Hygiene and Tropical Medicine under the direction of Prof. W. W. C. Topley; and of the physico-chemical phases, at the University of London, under the supervision of Prof. F. G. Donnan. No reports have as yet been made on this work.

The disposal of gas-works effluents has been studied by a Research Sub-Committee of the Institution of Gas Engineers.

The Effect of the Dilution Water on the Biochemical Oxygen Demand Determination[1]

BY H. HEUKELEKIAN[2] AND N. S. CHAMBERLIN[3]

There has recently been a great deal of experimentation and discussion with regard to the factors influencing the accuracy of the dilution method of determining biochemical oxygen demand. The interest has been due to the realization that, imperfect as it might be, this determination is one of the most valuable yardsticks for measuring the degree of purification in sewage treatment. Unfortunately there has been a lack of uniformity in some of the details of the procedure as carried out in different laboratories. The final solution of these difficulties will depend on extensive experimentation and not on an empirical basis. Preferably, the experimentation should be concerted action of a number of laboratories which have the facilities for extensive work. Then the problem can be attacked systematically and directly.

Without going into the numerous details of technique involved in the determination, which admittedly are of great importance, it seems to us that the question of the selection of a suitable dilution water is one of the most pressing problems. At present various dilution waters have been proposed and used in the various laboratories in this country. Some chemists are still using distilled water, which is severely criticized on account of its low salt concentration, which causes bursting of bacterial cells due to the differences in osmotic pressure within and without the bacterial cells. Distilled water consequently gives a lower B. O. D. With stream water and highly purified effluents the amount of test material introduced, in relation to the amount of dilution water, is probably sufficiently great to make the effect of distilled water a minor factor. However, with untreated sewage and especially with sludge samples, the B. O. D., when distilled water is used for dilution, is decidedly lower than it is when distilled water is supplemented with salts. Of the salts which are proposed largely on an empirical basis, mention might be made of $NaHCO_3$, $KHCO_3$, KH_2PO_4 and combination of salts in varying concentrations to make a more complete synthetic solution. Each synthetic water is of sufficient merit and promise to warrant further investigation before a final selection is made.

We believe that it will ultimately be necessary to compare these various waters with a selected standard. When, for instance, a certain water gives higher results than another one, it does not necessarily mean that

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such a water is of superior value, unless it can be shown that these higher results actually correspond to the ultimate B. O. D. The ultimate B. O. D., in our opinion, takes place in the receiving body of water; therefore, that artificial water is best which gives results comparable to those obtained by using water from the receiving body itself. For this reason we selected three streams in New Jersey which were representative of different sections and sufficiently divergent in their chemical characteristics so that we could show:

(1) Whether natural differences in the streams within a state cause appreciable differences in B. O. D. results, and

(2) Which of the artificial waters give results closest to those obtained with natural waters.

If the chemical variations of the different streams in a state cause decided differences in B. O. D. results, the question of selecting a rational standard dilution water, which will be applicable throughout the entire country, becomes too complicated. Hence, selection would have to be more or less arbitrary. If the differences in B. O. D. results are slight, the problem becomes simpler.

Method

The following waters were selected for comparison:

1. Stream water from Great Egg Harbor Creek near Weymouth, in the southern section of New Jersey.
2. Stream water from North Branch, a tributary to the Raritan, in the central section of the state.
3. Stream water from Pequest River, tributary to the Delaware, in the northern section of the state.
4. Sodium bicarbonate water — 100 p. p. m.
5. Sodium bicarbonate water — 500 p. p. m.
6. Synthetic water of the following composition, as suggested by Mohlman[1]:

$NaHCO_3$	65 p. p. m.
$CaCl_2$	10 p. p. m.
$CaSO_4$	15 p. p. m.
$MgSO_4$	10 p. p. m.

7. Phosphate water, as suggested by Theriault—42.5 p. p. m. of KH_2PO_4 neutralized with $N/1$ NaOH.
8. Distilled water.

Large quantities of the stream waters were brought into the laboratory July 21 and 22, 1930. They were filtered in order to remove foreign matter. Although the streams were selected for their comparative freedom from pollution, the waters were stored for two weeks before the first test was

[1] Memorandum Sanitary District of Chicago, Feb. 26, 1930.

run, in order to be sure that their original B. O. D.'s were completely satisfied. The same original water was used for all the series of tests in this study. The waters were analyzed in the beginning for *B. coli*, dissolved oxygen, pH value, alkalinity, acidity, total solids, ash, chlorides, sulphates, iron, calcium, magnesium and aluminium. The results are given in Table I.

The technique of the biochemical oxygen demand determinations was in accordance with "Standard Methods." The bottles containing the dilution water were gently rolled before use to prevent stratification. Separate dilutions were made outside in a cylinder and the material was syphoned into 250-cc., glass-stoppered bottles and constantly stirred. In each case, three dilutions were made, with two bottles for each dilution. Thus the results expressed in the tables are the averages of 6 determinations. The period of incubation was, in each case, 5 days at 20° C., in a carefully controlled incubator. Three series of tests were made with tank effluent and six series of tests with filter effluent. The sewage samples were obtained from Plainfield, New Jersey.

Results

The results of analyses of the original waters are given in Table I. The *B. coli* count is lowest in the Great Egg Harbor Creek water and highest in the Pequest River water; but even the latter, with 1300 *B. coli* per 100 cc., cannot be considered heavily polluted. The dissolved oxygen was likewise lowest in the Great Egg Harbor Creek samples and highest in those from the Pequest River. Unfortunately no B. O. D. determination was made on the original water, but assuming that it was 2 to 3 p. p. m. initially, and that on subsequent storage it was further reduced, the error in the diluted samples due to the B. O. D. of the water itself could not amount to more than only a small percentage. As shown in Table II, the dissolved oxygen increased on storage in all the waters until equilibrium was established around 7.0 p. p. m. These larger quantities of water could not be kept in our small 20° C. incubator; they were stored in the room and were therefore subject to fluctuations of the summer temperature. The small fluctuations in dissolved oxygen content after 30 days' storage should be explained on this basis. The pH values of the original dilution waters, as well as the effect of the 5-day incubation of different dilutions on the pH values of the original water, are shown in Table III. The pH value of the water from Great Egg Harbor Creek was the lowest and that from Pequest River, the highest. These values did not change materially during storage. It will be seen that there was a tendency for the pH values of the diluted samples to decrease. This effect was somewhat more pronounced in the tank effluent samples than in the filter effluent samples, but in no case, with the possible exception

TABLE I

ANALYSES OF THE STREAM WATERS

	B. coli, per 100 Cc.	Diss. O, P.p.m.	pH	Alkalinity, P.p.m. $CaCO_3$	Acidity, P.p.m. $CaCO_3$	Total Solids, P.p.m.	Vol. Matter, P.p.m.	Ash P.p.m.	Cl, P.p.m.	SO_4, P.p.m.	Fe, P.p.m.	Ca, P.p.m.	Mg, P.p.m.	Al, P.p.m.
Great Egg Harbor Creek	60	4.7	6.7	11	5	34	14	20	0.5	0	0.4	3.4	0.2	0.5
North Branch	600	5.4	7.5	68	7	120	38	82	1.5	31	0.3	23.0	5.9	1.6
Pequest River	1300	5.5	8.4	156	16	184	54	130	0	35	0	56.0	14.6	4.2

TABLE III

ORIGINAL pH VALUES OF THE DILUTION WATERS AND THE EFFECT OF THE 5-DAY INCUBATION OF DILUTED SEWAGE SAMPLES ON THE ORIGINAL pH VALUES

Series	Great Egg Harbor Creek			North Branch			Pequest River			$NaHCO_3$ Water, 100 P.p.m.			$NaHCO_3$ Water, 500 P.p.m.			Synthetic Water			KH_2PO_4 Water			Distilled Water		
	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.	Blank	Tank Effl.	Filter Effl.
1	6.5	6.2	6.4	7.3	6.9	7.1	8.3	7.5	7.8	7.5	6.9	7.2	8.4	7.6	7.8	7.2	6.7	6.9	7.8	7.1	7.6	6.4	6.3	6.2
2	6.5	6.4	6.4	7.5	7.2	6.7	8.3	7.5	7.6	8.0	7.2	7.0	8.4	8.0	8.0	7.4	8.0	6.9	7.4	7.0	6.9	6.0	6.3	6.6
3	6.6	6.3	6.8	7.6	7.0	7.5	8.4	7.7	8.3	7.9	7.0	7.5	8.3	8.0	8.1	7.9	7.0	7.3	7.6	6.9	7.3	6.9	6.3	6.8

Series 1 — dilution of tank effl. = 3%; filter effl. = 8%.

Series 2 and 3 — dilution of tank effl. = 4 5%; filter effl. = 10%.

of the Great Egg Harbor Creek water, were the pH values low enough to become a limiting factor.

The B. O. D. values of three different runs with the tank effluent, employing the different dilution waters, are given in detail in Table IV. It was considered of interest, in order to determine the accuracy of the method, to calculate the percentage variation of the duplicates from the

TABLE II

CHANGES IN DISSOLVED OXYGEN OF THE ORIGINAL STREAM WATERS DURING INCUBATION

Days	0	10	16	22	30	36	43	50
Great Egg Harbor Creek	...	4.7	5.6	6.0	7.2	6.8	6.7	7.0
North Branch	...	5.4	5.9	6.3	7.0	6.9	7.3	7.4
Pequest River	...	5.5	6.2	6.3	6.7	6.9	7.2	7.2

average of each dilution. These figures are represented in Table V, as plus and minus deviations from the averages. It will be readily seen that with a few exceptions the variations in the majority of the determinations did not exceed 6 per cent. If the results were to be interpreted on the basis of one run, the average variation for the different dilutions would be between 2 and 5 per cent, the average for the three runs would be 3.5 per cent. In determining the value of different dilution waters variations of less than 5 per cent are therefore not significant. The summarized results for the tank effluent are given in Table VI. The average B. O. D. of the three runs with the Great Egg Harbor Creek water was 122 p. p. m.; with North Branch, 156 p. p. m.; and with Pequest River, 182 p. p. m. The average B. O. D. obtained with the water from North Branch was 28 per cent higher than that from Great Egg Harbor Creek; and from Pequest River, 17 per cent higher than that from North Branch. These differences are beyond the limit of experimental error and should be attributed to the chemical composition of the waters.

With the artificial waters, the lowest value was obtained with distilled water, closely followed by 500 p. p. m. sodium bicarbonate water; the synthetic, phosphate and 100 p. p. m. sodium bicarbonate waters gave somewhat higher results but the differences were not large. There was a difference of only 10 p. p. m. between the results with distilled water, which were the lowest, and the results with 100 p. p. m. sodium bicarbonate water, which were highest. Both of these waters differed by only 5 per cent from the averages with the artificial waters. The synthetic water, which had a greater variety of ions, did not give higher results than the 100 p. p. m. sodium bicarbonate water and none of the artificial waters gave as high results as two of the natural waters but were more comparable to the acid water of Great Egg Harbor Creek.

TABLE IV

FIVE-DAY B. O. D. OF TANK EFFLUENT WITH VARIOUS DILUTION WATERS

Per Cent Dilution	Series 1 1.5%, P. p. m.	Series 1 3.0%, P. p. m.	Series 1 4.5%, P. p. m.	Series 1 Avg., P. p. m.	Series 2 1.5%, P. p. m.	Series 2 3.0%, P. p. m.	Series 2 4.5%, P. p. m.	Series 2 Avg., P. p. m.	Series 3 1.5%, P. p. m.	Series 3 3.0%, P. p. m.	Series 3 4.5%, P. p. m.	Series 3 Avg., P. p. m.
Great Egg Harbor Creek	123 117	91 95	90 88		185 173	140 158	139 149		... 110	105 111	108 111	
Avg. of duplicates	120	93	89	100	179	149	144	157	110	108	110	109
North Branch	133 113	100 103	95 95		220 240	203 195	... ...		163 157	148 150	135 132	
Avg. of duplicates	123	101	95	106	230	199	...	215	160	149	134	148
Pequest River	187 200	133 137	130 120		243 243	218 225	... ...		180 182	170 170	143 131	
Avg. of duplicates	193	135	125	151	243	222	...	233	181	170	137	163
$NaHCO_3$ water 100 p. p. m.	90 77	82 88	85 85		150 157	173 160	164 166		127 124	138 130	124 114	
Avg. of duplicates	83	85	85	84	154	167	165	162	126	134	119	126
$NaHCO_3$ water 500 p. p. m.	83 70	125 85	83 92		157 140	142 150	145 142		... 117	125 128	122 119	
Avg. of duplicates	76	105	87	89	149	146	144	146	117	126	121	121
Synthetic water	87 67	87 83	91 87		170 177	180 170	163 160		110 110	108 100	114 108	
Avg. of duplicates	77	85	89	84	174	175	162	170	110	104	111	108
Phosphate water	107 107	67 90	87 70		177 157	180 175	170 166		93 100	115 107	119 109	
Avg. of duplicates	107	78	78	88	167	178	168	171	97	111	114	108
Distilled water	60 70	77 78	77 82		133 153	150 145	163 156		123 134	108 122	114 116	
Avg. of duplicates	65	77	79	74	143	148	160	150	128	115	115	119

TABLE V

DEVIATIONS OF THE DUPLICATES FROM THE AVERAGE OF EACH DILUTION (EXPRESSED AS PLUS AND MINUS PERCENTAGE)

Per Cent Dilution	Series 1 1.5	Series 1 3.0	Series 1 4.5	Series 1 Avg.	Series 2 1.5	Series 2 3.0	Series 2 4.5	Series 2 Avg.	Series 3 1.5	Series 3 3.0	Series 3 4.5	Series 3 Avg.	Avg. Deviation of All 3 Series
Great Egg Harbor Creek	2.5	2.1	1.0	1.9	3.3	6.4	3.5	4.4	...	2.8	1.8	2.3	2.9
North Branch	8.1	2.0	0	3.4	4.3	2.0	...	3.1	1.9	0.7	0.8	1.1	2.5
Pequest river	3.1	1.5	4.0	2.9	0	1.6	...	0.8	0.5	0	4.2	1.6	1.9
$NaHCO_3$ water 100 p. p. m.	7.8	3.5	0	3.8	2.3	3.9	0.6	2.3	0.9	3.0	4.2	2.7	2.9
$NaHCO_3$ water 500 p. p. m.	8.5	19.0	5.2	10.9	5.7	2.7	0.7	3.0	...	0.9	0.9	0.9	5.4
Synthetic water	13.0	2.3	2.2	5.8	2.0	2.9	0.9	1.9	0	3.8	2.7	2.2	3.3
Phosphate water	0	14.7	10.9	8.5	6.0	1.4	1.9	3.1	3.6	3.6	4.4	3.9	5.2
Distilled water	7.7	0	3.2	3.6	7.0	1.7	2.2	3.6	4.3	6.1	0.9	3.8	3.7
Average				5.1				2.8				2.3	3.5

Table VII represents the detailed results of 6 runs of B. O. D. determinations of filter effluent with the various dilution waters. Although the variations in p. p. m. in the B. O. D. values between the duplicates were closer in this case than in the study with tank effluent, the percentage variations as shown in Table VIII were higher, due to the smaller B. O. D.

TABLE VI

AVERAGE 5-DAY B. O. D. OF TANK EFFLUENT

	Series 1, P. p. m.	Series 2, P. p. m.	Series 3, P. p. m.	Avg. of All 3 Series, P. p. m.
Stream waters:				
Great Egg Harbor Creek	100	157	109	122
North Branch	106	215	148	156
Pequest River	151	233	163	182
Artificial waters:				
100 p. p. m. $NaHCO_3$	84	162	126	124
500 p. p. m. $NaHCO_3$	89	146	117	117
Synthetic water	84	170	108	121
KH_2PO_4 water	88	171	108	122
Distilled water	74	150	119	114

values. The highest average variation between the individual dilution waters for the 6 runs was 8.7 per cent and therefore variations lower than this are not significant in determining the value of the different dilution waters.

The summarized results are given in Table IX. Of the stream waters the average B. O. D. was lowest with the Great Egg Harbor Creek water, while the B. O. D.'s with water from the other two streams were identical. The difference amounted to 26 per cent, which is significant and must be attributed to the chemical composition of the waters. Of the artificial waters, the lowest B. O. D. value was again obtained with the distilled water, while the sodium bicarbonate water and the synthetic water gave high results, and the phosphate water gave intermediate results. The difference between the distilled water results, which were the lowest, and the synthetic water results, which were the highest, was 11 p. p. m. or 31 per cent. The variation of the results with distilled water from the average of all results with artificial waters was 17 per cent, which is considerably above the limit of experimental error. The distilled water in this case was comparable to the water from Great Egg Harbor Creek and the other artificial waters were in the range of the two more normal stream waters.

Discussion

As shown in Table I, the natural waters selected embraced a wide range of chemical conditions. The Great Egg Harbor Creek water was acid

TABLE VII

FIVE-DAY B. O. D. OF FILTER BED EFFLUENT WITH VARIOUS DILUTION WATERS

Per Cent Dilution	Series 1 5%, P. p. m.	Series 1 7.5%, P. p. m.	Series 1 10%, P. p. m.	Avg. of 3 dilutions, P. p. m.	Series 2 4%, P. p. m.	Series 2 6%, P. p. m.	Series 2 8%, P. p. m.	Avg. of 3 dilutions, P. p. m.	Series 3 4%, P. p. m.	Series 3 6%, P. p. m.	Series 3 8%, P. p. m.	Avg. of 3 dilutions, P. p. m.
Great Egg Harbor Creek	54 48	52 53	44 48		42.5 37.5	40 48	47.5 43.7		32 37	30 35	32 37	
Avg. of duplicates	51	52.5	46	50	40	44	45.6	43.3	34.5	32.5	34.5	33.8
North Branch	62 62	73 65	58 57		53.7 57.5	56.6 56.6	65 73.7		35.0 30	33 35	45 42	
Avg. of duplicates	62	69	57.5	63	55.6	56.6	69.3	60.5	32.5	34	38	34.8
Pequest River	70 78	60 63	56 54		57.5 67.5	60 60	60 55		40 37.5	35 33	39 47.5	
Avg. of duplicates	74	61.5	55	63	62.5	60	57.5	60.0	39	34	43	38.7
$NaHCO_3$ water—100 p. p. m.	72 64	.. 56	62 58		47.5 52.5	58.3 65	60 53.7		20 20	33 48	30 31	
Avg. of duplicates	68	56	60	61	50.0	61.5	56.8	56.1	20	40	30	30
$NaHCO_3$ water—500 p. p. m.	.. 60	63 55	59 55		65 62.5	65 66.6	65 62.5		45 42.5	38.3 38.3	45 41	
Avg. of duplicates	60	59	57	59	63.7	65.8	63.7	64.4	43.7	38.3	43	41.7
Synthetic water	78 68	66 53	58 62		57.5 52.5	70 68.3	58.7 60.0		47.5 47.5	35 35	40 ..	
Avg. of duplicates	73	60	60	64	55.0	69.1	59.3	61.1	47.5	35	40	37.5
Phosphate water	56 ..	45 56	55 56		47.5 40.0	55.0 61.6	50 58.7		45.0 30	31.7 45.0	29.0 27.0	
Avg. of duplicates	56	50	55	54	43.7	58.3	54.4	52.1	37.5	38.5	28.0	34.7
Distilled water	52 54	57 59	53 61		20.0 20.0	40.0 30.0	45.0 47.5		45 35	28 28	31 30	
Avg. of duplicates	53	58	57	56	20.0	35.0	46.2	33.4	40	28	30.5	33.5

Per Cent Dilution	Series 4 5%, P. p. m.	Series 4 7.5%, P. p. m.	Series 4 10%, P. p. m.	Avg. of 3 dilutions, P. p. m.	Series 5 5%, P. p. m.	Series 5 7.5%, P. p. m.	Series 5 10%, P. p. m.	Avg. of 3 dilutions, P. p. m.	Series 6 5%, P. p. m.	Series 6 7.5%, P. p. m.	Series 6 10%, P. p. m.	Avg. of 3 dilutions, P. p. m.
Great Egg Harbor Creek	43 47	43 43	42.5 45.5		23 29	29 24	23 21		28 31	39 32	39 38	
Avg. of duplicates	45	43	44	44	26	27	22	25	30	36	39	35
North Branch	44 56	45 44	46 47		31 26	30 35	24 22		52 52	59 56	48.5 47.5	
Avg. of duplicates	50	44.5	46.5	47.0	29	33	23	28	52	58	48	53
Pequest River	50 56	50 48	46 51		22 26	25 29	19 19		46 53	.. 57	59 55	
Avg. of duplicates	53	49	48.5	50.0	24	27	19	23	50	57	57	55
$NaHCO_3$ water—100 p. p. m.	35 43	55 39	48.5 54.5		29 32	22 21	20 27		51 53	47 45	50 50	
Avg. of duplicates	39	47	51	46.0	31	22	24	26	52	46	50	49
$NaHCO_3$ water—500 p. p. m.	39.0 35	34 35	38.5 40.5		18 20	17 ..	18 17		44 42	43 48	47 44	
Avg. of duplicates	37	34.5	39.5	37.0	19	17	18	18	43	46	46	45
Synthetic water	42 46	55 40	41 42		30 26	30 26	17 21		44 44	41 50	41 43	
Avg. of duplicates	44	47.5	41.5	44.3	28	28	19	25	44	45	42	43
Phosphate water	48 38	43 47	43 42		24 23	28 40	26 21		32 40	40 41	42 38	
Avg. of duplicates	43	45	42.5	43	24	34	24	27	36	40	40	39
Distilled water	34 25	32 41	45.5 37		19 21	19 13	16 18		33 30	34 37	36 34	
Avg. of duplicates	29.5	36.5	41	36	20	16	17	18	32	35	35	34

in character, had a low alkalinity and had a low total solid content. The Cl, SO_4, Fe, Ca, Mg and Cl ions were present in very low concentrations. The water from Pequest River was alkaline in reaction, had the highest solid content and had high SO_4, Ca, Mg and Al ion concentrations. Chlorides and iron were absent. The North Branch water was of an intermediate character in these respects. The average B. O. D. values with the tank effluent and the filter effluent, as given in Tables VI and IX, respectively, indicate an interesting relationship between the chemical compositions of these natural waters. In both cases the Great Egg Harbor Creek water gave the lowest results. The North Branch water gave intermediate results and Pequest River the highest results with the tank effluent. With the filter effluent, however, there was no difference between the two latter waters. It is possible that, with the filter effluent, the amount of different salts introduced with the high percentages of sewage was enough to mask the original differences in the composition of the North Branch and Pequest River waters. The Great Egg Harbor Creek water, however, was so deficient in soluble salts that the salts introduced in the sewage sample were not sufficient to overcome the deficiency. It seems then that the natural chemical variation of stream water, even within a state, exerts appreciable influence on the B. O. D. results. It is true that we have in these three streams wide divergence in chemical compositions. The Great Egg Harbor Creek water should be considered as

TABLE VIII

DEVIATIONS OF THE DUPLICATES FROM THE AVERAGES OF EACH DILUTION (EXPRESSED AS PLUS OR MINUS PERCENTAGE)

Per Cent Dilution	5.0	7.5	Series 1 10	Avg. of 3 dilutions	5.0	7.5	Series 2 10	Avg. of 3 dilutions	5.0	7.5	Series 3 10	Avg. of 3 dilutions	5.0	7.5	Series 4 10	Avg. of 3 dilutions	5.0	7.5	Series 5 10	Avg. of 3 dilutions	5.0	7.5	Series 6 10	Avg. of 3 dilutions	Total Avg.
Great Egg Harbor Creek	5.9	0.9	4.3	3.7	6.2	8.3	4.1	6.2	7.2	7.7	7.2	7.4	4.4	0	3.4	2.6	11.5	9.3	4.5	8.4	5.0	9.7	1.3	5.3	5.6
North Branch	0	5.8	0.9	2.2	3.4	0	6.3	3.2	7.7	2.9	17.1	9.2	12	0	1.1	4.7	8.6	7.5	4.3	6.8	0	2.6	1.0	1.2	4.5
Pequest River	5.4	2.4	1.8	3.2	8.0	0	4.3	4.1	3.2	2.9	0.3	5.1	5.6	2.0	5.1	4.2	8.3	7.4	0	5.2	7.0	..	3.5	5.2	4.5
$NaHCO_3$ water, 100 p.p.m.	5.9	..	3.3	4.6	5.0	5.7	5.4	5.4	0	18.7	1.7	6.8	10.5	17.0	6.9	11.5	4.8	2.3	14.6	7.2	1.9	2.2	0	1.4	6.1
$NaHCO_3$ water, 500 p.p.m.	...	6.8	3.5	5.1	1.9	1.2	1.9	1.7	2.7	0	4.6	2.4	5.4	1.4	2.5	3.1	5.2	..	2.8	4.0	2.3	5.4	3.2	3.6	3.3
Synthetic water	6.8	12.5	3.3	7.5	4.5	1.3	1.2	2.3	0	0	..	0	4.5	15.8	1.2	7.2	7.1	7.1	10.5	8.2	0	12.2	2.4	4.9	5.0
Phosphate water	...	11.0	0.9	6.0	8.4	5.6	8.1	7.4	20.0	17.1	3.6	13.6	11	6	4.4	1.2	5.7	2.1	17.6	10.4	10.0	11.1	12.5	5.0	9.5	8.7
Distilled water	1.9	1.7	7.0	3.5	0	14	3	2.6	5.6	12.5	0	1.6	4.7	15	3	12.4	9.8	12.5	5.0	18.7	5.9	9.9	4.7	4.3	2.8	3.9	6.7
Avg. for each series				4.3				4.3				6.1				6.4				7.5					4.4	5.0

abnormally deficient in chemical salts. Still, with even normal variations in the composition of stream water, differences in the B. O. D.'s are to be expected, especially when streams carry material with a high B. O. D., such as raw sewage and sludge.

In comparing the B. O. D. values obtained with the artificial waters our results confirm previous work showing that distilled water gives low

TABLE IX

AVERAGE 5-DAY B. O. D.'S OF FILTER EFFLUENTS

Series	Series 1, P. p. m.	Series 2, P. p. m.	Series 3, P. p. m.	Series 4, P. p. m.	Series 5, P. p. m.	Series 6, P. p. m.	Avg. of All Series, P. p. m.
Stream waters:							
Great Egg Harbor Creek	50	43	34	44	25	35	38
North Branch	63	60	35	47	28	53	48
Pequest River	63	60	39	50	23	55	48
Artificial waters:							
100 p. p. m. $NaHCO_3$	61	56	30	46	26	49	45
500 p. p. m. $NaHCO_3$	59	64	42	37	18	45	44
Synthetic water	64	61	37	44	25	43	46
KH_2PO_4 water	54	52	35	43	27	39	41
Distilled water	56	33	33	36	18	34	35

results. The 500 p. p. m. $NaHCO_3$ water gave somewhat lower results than the 100 p. p. m. $NaHCO_3$ water, especially with the tank effluent. This would indicate that if $NaHCO_3$ water is to be used it is better to select a lower concentration than 500 p. p. m. However, the differences between the various artificial waters were not sufficiently great to be determining factors in selecting any one of them. The important fact seems to be that, with the tank effluent, none of the artificial waters gave as high results as the better natural waters; while, with the filter effluent, the B. O. D. values obtained with the artificial waters came closer to those obtained with the two better natural waters. This must again be ascribed to the overshadowing influence of the salts in the sewage introduced in the higher percentage dilutions.

The important factors which determine the value of a dilution water are:

1. The pH and buffering values.
2. The variety and concentration of ions for maintaining the necessary osmotic pressure and furnishing the necessary nutrition for bacteria.

The Great Egg Harbor Creek water and distilled water were lacking in both of these respects. In the other natural and artificial waters the pH and buffer values were well regulated. That the ionic concentration was an important factor is born out by the chemical analyses of the three natural waters and their respective B. O. D. values. That the variety of ions is also an important factor is shown by comparing the B. O. D. values of the natural waters with those of the artificial waters. The single salt

dilution waters would probably maintain the necessary osmotic pressure but would not furnish the variety of ions for the growth of bacteria. It would be hard to reconcile the fact that the synthetic water which carried a variety of ions did not give any better results than the single salt dilution waters, without assuming that either essential ions were lacking in the latter or that they were not present in sufficient concentrations in the former. It is possible that certain other considerations have been overlooked which might make the stream waters more satisfactory for dilution purposes than the artificial waters. Of these, mention might be made of the bacterial flora of the stream waters and certain growth-promoting substances. It would seem that the organisms introduced by the test materials should furnish adequate inoculation, but when high dilutions are made with artificial waters, this might become a limiting factor.

It would be possible to develop, with further research, an artificial water with greater complexity of ions. A synthetic water containing sewage salts might even be made by drying and igniting a portion of the sewage and introducing it into the dilution water. A water of this kind, however, will give results comparable to those obtained with some stream waters but they will be, for the most part, low or high in comparison with other streams. It would be desirable if a single uniformly satisfactory dilution water could be found but the variety of purposes for which such a water is used seems to make that impracticable.

The B. O. D. determinations are made for the following purposes:

A. Stream pollution studies.
   1. B. O. D. of the river water itself.
   2. B. O. D. load of a sewered community emptying either raw or partially treated sewage into a stream.

B. Plant efficiency studies.
   1. Efficiency of a unit or an entire treatment works, in regard to B. O. D. reduction.
   2. B. O. D. values of sludges.

As has been already pointed out, in the determination of the B. O. D. of a river water itself the dilution water is either not used at all or used in small quantities and can therefore be eliminated from consideration in this discussion. It is only when material of higher B. O. D. value is tested and found to require greater dilution that the character of the dilution water becomes important. The higher the B. O. D., therefore, the greater the influence of the dilution water will be. For the determination of the pollution load on a river by a sewered community, the unpolluted water in the upper stretches of the river should undoubtedly be used for dilution purposes. Such a water, if procurable, should be stored in order to stabilize its own demand. The use of such a water would eliminate the errors usually introduced by a dilution water. On

the other hand, results of such studies in different sections of the country cannot be compared closely because of the chemical variation of stream waters. However, in studies conducted for theoretical purposes or for plant efficiency, determinations could be made with a standard dilution water. Such results, although only relative, could be compared directly. The problem, therefore, seems to have resolved itself into two distinct phases. When it comes to stream pollution studies, the problem of getting a standard dilution water is apparently too complex. For plant efficiency and theoretical studies, however, some research along the lines mentioned above might bring forth a standard dilution water.

Summary and Conclusions

The effect of various dilution waters on the B. O. D. values of tank effluent and filter effluent was studied. Three stream waters from New Jersey and five artificial waters were compared, in a number of determinations. The following conclusions may be drawn from the results:

1. There was a pronounced difference in the B. O. D. values when the three stream waters were used for dilution.
2. The stream water with the lowest salt concentration gave the lowest B. O. D. values.
3. Distilled water also gave low B. O. D. results.
4. The differences in the B. O. D. values, when the artificial waters were used, were not pronounced.
5. The B. O. D. values of the tank effluent, when the artificial waters were used for dilution, were comparable to the values obtained by the use of the chemically deficient stream water for dilution.
6. The B. O. D. values of filter effluent, with artificial dilution waters, were comparable to the values obtained by the use of the better stream water for dilution.
7. The salts in the sewage samples, especially where the B. O. D. is low and greater concentrations of sewage exist, overshadow the effect of the salts in the various artificial dilution waters.
8. By increasing the chemical composition of the artificial waters qualitatively and quantitatively, the effect of salts introduced by the sewage itself might be obliterated.
9. In determining the B. O. D. load of a stream, water from the unpolluted portion of the stream itself might be used for dilution purposes, since the variations in chemical compositions of streams influence the B. O. D. values.
10. For theoretical and plant efficiency studies, a standard dilution water of certain salt concentration, and containing a greater variety of ions than those found in any of the present dilution waters, should be developed.

Studies on the Treatment of Combined Sanitary Sewage and Milk Waste

BY E. F. ELDRIDGE* AND W. E. ZIMMER**

Many municipalities are confronted with the problem of treating a combined sewage consisting of the ordinary sanitary sewage and a large proportion of milk waste. The problem is usually confined to the small municipality. Some of these have constructed plants with no idea as to what results might be expected, but following the usual design for sanitary sewage disposal. In some cases trouble has been experienced in the operation of these plants.

With the idea of developing suggestions for the design of treatment plants to handle combined sewage of this nature, the Engineering Experiment Station, in coöperation with the city of Mason, Michigan, conducted experiments, the results of which are given below. These studies were made during the summer of 1930.

Sewage

The sewage of the City of Mason consists of the combined sanitary sewage from a population of 1500 people and the milk waste from a large milk products plant handling upward of 120,000 pounds of milk daily. The sanitary sewage is comparatively strong, due to the lack of infiltration in the sewer system. The volume of sewage averages about 225,000 gallons daily. The milk waste is comparatively weak for a waste of this kind, but large in volume, as it contains the condenser water from a vacuum pan which is operating 12 to 16 hours daily. The average volume of this waste is 225,000 gallons.

The combined sewage, therefore, is approximately 50 per cent sanitary sewage and 50 per cent milk waste. Both the strength, as measured by the 5-day biochemical oxygen demand, and the volume are extremely variable. The average B. O. D. for a combined morning flow is about 450 p. p. m. and for the afternoon about 750 p. p. m. This difference is due to the fact that the strongest milk waste does not reach the plant until after 12:00 noon and to the dilution of the early morning flow with water containing little, if any, milk. A typical analysis of a daily composite is shown in Table I.

Primary Treatment

The character of milk waste is such that very little material can be removed by settling unless the acidity of the waste is increased to the point where casein is precipitated. This acidity is, of course, undesirable. For this reason primary treatment by settling has very little effect upon the

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milk solids contained in the combined waste. Settling, however, is necessary for the removal of the suspended sewage solids. The question of primary treatment resolves itself into a balance between the time necessary for proper settling and that necessary for the souring of the milk waste.

The pH of the effluent from the settling tanks should not be lower than 6.6 to 6.8, if filtration is to follow. The studies at Mason showed that

TABLE I

TYPICAL ANALYSIS OF COMBINED SEWAGE

	Influent to Tank, P. p. m.	Effluent of Tank, P. p. m.
Total solids	1160	800
Loss on ignition	840	500
Suspended solids	290	75
pH	6.9	6.7
Oxygen consumed	180	120
B. O. D.	600	480

a time interval of $2^1/_2$ to 3 hours could be allowed between the discharge of the milk waste at the milk plant and the application of the settling tank effluent to the filters. Thus at Mason approximately 50 minutes to 1 hour was required for the milk waste to flow from the plant through the sewer to the treatment plant. This left an allowable detention period in the tanks of $1^1/_2$ to 2 hours. The actual detention period was somewhat less, but satisfactory settling was always obtained. At no time, using this settling period, did the pH drop below 6.7.

Sludge Digestion

The next question relates to the effect of the milk solids on the digestion of the sludge from the settling tank. It was thought that perhaps regulation of the pH would be necessary or, at least, advantageous with this type of sludge. Samples of the fresh solids were collected in pails suspended in the tanks. These samples were composited and analyzed for solids content. A measured quantity (1500 cc.) of the well-mixed sludge was placed in each of six 3-liter bottles. These bottles were connected with cylinders for the collection and measurement of gas and were fitted with tubes from which samples could be drawn for analysis.

Two of these samples were allowed to digest without control, two were adjusted to a pH of 7.2 to 7.4 with calcium carbonate, and the last two were adjusted to 7.4 to 7.6 in the same manner. A temperature of 75° F. was used for the digestion. Adjustments and gas readings were made daily.

At first there was very little gas production due to the lack of digested sludge in the samples. During this development of digestive bac-

terial flora the pH of the uncontrolled samples dropped to as low as 6.1 and much difficulty was experienced in keeping the controlled samples at the desired pH. About 20 to 25 days were required for the development of the anaerobic flora and, as is shown on Chart 1, very little advantage in pH control was apparent. After digestion started, however, the pH of the uncontrolled samples increased to about 6.9 to 7.1. Gas production in the controlled samples increased more rapidly than in the uncontrolled,

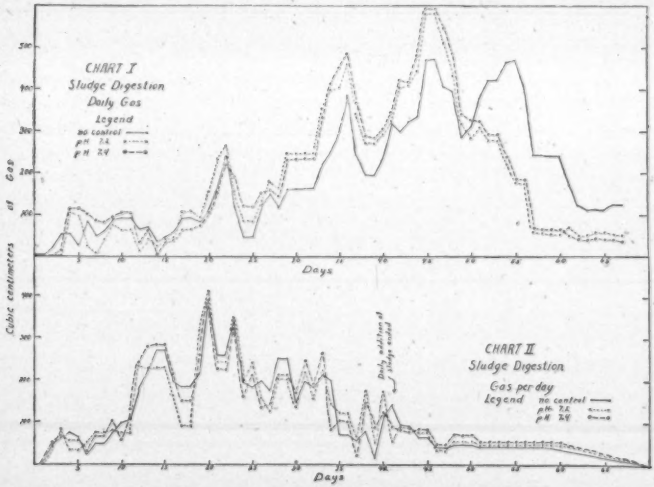

CHART I.—Gas Production, Solids from Combined Sewage and Milk Waste, with and without pH Adjustment, Single Initial Charge.

CHART II.—Gas Production, Solids from Combined Sewage and Milk Waste, with and without pH Adjustment, Daily Charges.

reaching a much larger daily volume and complete production in a much shorter period. About 20 days were required for the controlled and 27 days for the uncontrolled to complete the larger part of the digestion. The total volume of gas at the end, however, was approximately the same.

After carrying these samples through for 67 days, at which time the digestion was almost complete, a second series of experiments was started by adding a known weight of fresh sewage daily to the digested sludge. This series was planned to approximate the actual manipulation of a separate sludge-digestion plant. Addition of sludge was continued each day for 41 days and adjustments and readings taken as before.

Chart 2 shows the daily gas production for this series. As will be seen, there was very little advantage obtained from the adjustment of the pH. The uncontrolled samples had a very constant pH value between 7.0 and 7.2. The other two were adjusted to 7.2 and 7.4, respectively. Twenty-nine days after the last sludge was added the digestion was complete.

From a study of the charts the large variation in the gas produced from day to day is apparent. From observation made during these and other studies, it would seem that atmospheric conditions, particularly barometric pressure, have some effect. In almost all cases the high and low points appear in all samples at the same time.

These studies show that very little advantage was obtained from the adjustment of the pH of these sludges once the digestion had started. There is, however, an advantage in keeping the pH up by adjustment during the accumulation of the digestive flora in normal fresh sewage sludge.

Table II gives the compiled data from the complete series of experiments. The average volume of gas per pound of dry sludge in this case was about 3.85 cubic feet.

TABLE II
SLUDGE DIGESTION DATA

	Uncontrolled Sample	pH 7.2–7.4	pH 7.4–7.6
Total wt. of sludge	120 gm.	120 gm.	120 gm.
Total vol. of gas	29,580 cc.	28,450 cc.	28,640 cc.
Vol. of gas per gm. of sludge	246 cc.	237 cc.	238 cc.
Vol. of gas per pound of sludge	3.9 cu. ft.	3.8 cu. ft.	3.8 cu. ft.

Secondary Treatment

At the present time the effluent from the settling tanks at Mason does not receive secondary treatment. For the purpose of carrying on these studies a small filter was installed at the disposal plant. It was constructed on a ten-foot circular concrete base and was composed of graded gravel ($1^1/_2$ to 3 inches in diameter) ten feet deep, held in place with chicken and fence wire. Sampling points were provided at foot intervals by laying troughs in the gravel as the filter was being built. The effluent was pumped from the outlet trough of the settling tanks to an orifice box, from which a measured quantity flowed into a dosing tank. The dosing tank was provided with a float and flush valve which operated at intervals giving intermittent dosing. The dosing tank was connected with a revolving arm sprinkler for distribution of the waste on the filter.

The points to be determined by this set of experiments were: What

rate of application of this combined waste could be used; and what was the minimum depth of filter required for practical efficient operation.

The filter was operated constantly twenty-four hours a day during the summer. The rates were varied at times and composite samples collected every few days for analysis. Continuous sampling was effected by allowing a small portion to drip through a hole punched in each trough.

The rate of application was varied from 1 to 2.2 million gallons per acre per day (m. g. a. d.). The results are shown by the curves in Chart III. These curves represent the percentage reduction in the B. O. D. for three rates, 1,000,000, 1,300,000 and 2,200,000 gallons per acre per day. In selecting the rates to be used an attempt was made to get rates of 1.0, 1.5 and 2.0 m. g. a. d., but by measurement it was found that the above rates were actually obtained.

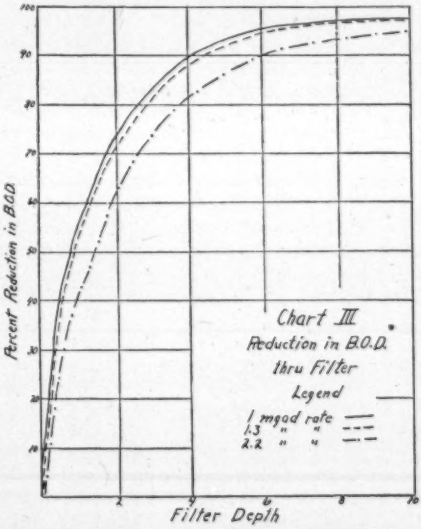

CHART 3.—Reduction of B. O. D. at Various Depths of Trickling Filter Operated at 1.0, 1.3 and 2.2 M. G. A. D.

These results show that with a 1.0 m. g. a. d. rate practically all of the oxygen demanding materials were removed in the first 6 feet of filter. The effluent from the 6-foot sampling point always had a relative stability with methylene blue to exceed 10 days. The average reduction in B. O. D. was from 390 to 14 p. p. m. in 6 feet. The pH of the effluent applied to the filter varied between 6.7 and 7.3. When operated at 1.3 m. g. a. d. the reduction of B. O. D. was from 261 to 16 at 6 feet. In this run, the average waste was somewhat lower in B. O. D. than in the previous experiment at the lower rate. At the 2.2 m. g. a. d. rate the reduction was from 395 to 40 p. p. m. at the 6 foot and to 28 p. p. m. at the 8-foot depth. The depth of filter must therefore be greater at the higher rate if the same stability of effluent is to be obtained.

The depth of filter will, of course, depend upon the stability of effluent desired. The combined sewage, after settling, will be higher in B. O. D. than from normal sanitary sewage and will require either a deeper filter or a lower rate or both. From the above studies, it is shown that at a rate of about 1.5 m. g. a. d. good effluents can be obtained from a filter 6 to 7 feet deep. With a rate of from 2 to 2.2 m. g. a. d. a 7- to 8-foot filter will be required for the same degree of treatment.

Conclusions

The following conclusion on the treatment of combined milk waste and sanitary sewage can be drawn from these studies:

1. Primary settling may be accomplished satisfactorily if the detention period plus the time required for the milk waste to reach the plant does not exceed $2^1/_2$ to 3 hours.
2. Milk solids will not settle; therefore, the percentage reduction of B. O. D. through the tank will not be as great as with sanitary sewage alone, and the B. O. D. of the effluent will be correspondingly higher.
3. Separate sludge digestion is desirable. This can be carried on in a tank separate from the settling tank or in the lower compartment of an Imhoff tank.
4. Regulation of the pH of the sludge is advantageous only during the first stages of digestion.
5. The rate of filtration and depth of filter for the oxidation of the effluent from primary settling depends upon the degree of treatment desired. Stable effluents can be obtained with a 6- to 7-foot filter operated at 1.5 m. g. a. d. rate, or a 7- to 8-foot filter operated at a 2 m. g. a. d. rate.

A Comparison of Two Methods for Determination of Hydrogen Sulphide in Sewage

BY HARRY E. JOHNSON*

Two methods for determination of hydrogen sulphide in sewage have been investigated at the Flint, Michigan, sewage treatment works. The methods studied were:

A. The iodine titration method, in which the difference in c.c. of *N*/40 iodine solution absorbed by a thoroughly aerated portion and an unaerated portion of sample is recorded. This difference, assumed to be that consumed in hydrogen sulphide destruction, when multiplied by an appropriate factor gives the hydrogen sulphide content.

B. The antimony tartrate method, in which a solution of antimony potassium tartrate is added to the sample, a yellow color resulting in the presence of sulphides (antimony sulphide). The sulphide content is determined by comparing the sample with standards. The method applied to aerated and unaerated samples will give volatile sulphide by difference. (See "The Antimony Method for Sulphide Determination," Salle and Reinke, *Calif. Sewage Works Jour.*, **1929,** p. 208).

Discussion

Both methods were accurate when applied to samples of distilled water containing sulphides. When applied to Imhoff tank effluents, however, both methods appeared to be inaccurate. The iodine method indicated higher sulphide values than were actually present. The antimony method entailed a great deal of guesswork in matching the permanent standards and unknown samples. On samples containing less than 3 p. p. m. sulphide sulphur both methods were equally and sufficiently accurate. With the antimony method the lighting effect was important. The nature of the original standards presented a difficulty in that they contained colorless turbidity (silica) in yellow dichromate solutions, while the sewage samples contained colored precipitate in a slightly colored medium.

The preparation of standards from water containing sulphide and development of the color-suspension with antimony tartrate addition proved more satisfactory. The standards were prepared from standard sodium sulphide solution ($Na_2S{:}9H_2O$) contained in 0.01% sodium hydroxide solution. The standards were acidified after adding the antimony tartrate and the yellow precipitate resulted. However, the color under some conditions would hold up for only a few hours. Under favorable conditions the standards would hold up for about 12 hours but after this time flocculation of the precipitate would take place, thus impairing the accuracy of the standards.

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The addition of a protective colloid (gelatine) to prevent flocculation of the precipitate was next tried. It was found that the addition of gelatine to the sulphide water, prior to antimony tartrate addition, entirely prevented the formation of a colored precipitate but instead a clear amber color developed, which varied with the amount of sulphide present. This color closely matched the color of potassium dichromate in proper dilutions. Standards prepared from potassium dichromate and superimposed over blank sewage samples gave results accurate to 0.25 or 0.5 p. p. m. in sulphide concentrations up to 5.0 p. p. m., when the proper amount of gelatine had been added to the tartrate reagent. The method would give even more accurate results where sulphide is to be determined in clear filtrates, since long Nessler tubes could be used for color comparison.

In the study of the iodine method it was found that the titration endpoint was difficult to determine in sewage which was alkaline or concentrated. The results obtained were generally higher than the known sulphide added should have produced. Slight acidification of the samples with dilute acid just prior to the titration with an excess of $N/40$ iodine solution, followed by destruction of the excess with $N/40$ thiosulphate, followed by back titration with iodine solution, produced sharp and permanent starch-iodide endpoints. If the procedure was followed with care, the method was accurate to 0.2 p. p. m.

Previously studies had been made of aspiration of the volatile sulphides into standard iodine solution and into a weak sodium hydroxide solution. Of the two absorbing mediums the caustic solution gave the best results, since the iodine loss from a $N/40$ solution on 10 minutes aeration was about 50 per cent. However, the amount of hydrogen sulphide collected in the caustic was only from 50 to 80 per cent of that aspirated from the hydrogen sulphide water.

Recommended Methods for Sulphide Determination

I. Modified Antimony Tartrate Method

Reagents:

1. Antimony potassium tartrate solution. Dissolve 50.0 grams of the tartrate (commonly known as tartar emetic) in 900 cc. of distilled water. After solution is complete add 10.0 grams of pure gelatine (ordinary unflavored cooking gelatine is satisfactory). Let stand a few minutes to soften the gelatine, after which warm slightly on a water bath until the contents are completely dissolved. Cool and make to 1 liter. Add about 1 cc. of formaldehyde to preserve the reagent.
2. Hydrochloric acid solution—1 c. p. acid to 1 water.
3. Sodium chloride—dry crystals.
4. Potassium dichromate solution—0.25 grams per liter. (Same as in Standard Methods for chlorine.)

Standards:

Use 6.8 cc. of the potassium dichromate solution (4) for each p. p. m. sulphur. Make up to 100 cc. in 4-ounce, clear glass bottles. Prepare standards of 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0, p. p. m. sulphur.

Sampling:

In collecting samples precaution must be taken to guard against aeration and loss of volatile hydrogen sulphide. Crude sewage should be allowed to settle and the supernatant taken for the test. If samples are to be transported prior to testing, sufficient caustic soda solution (5%) should be added to render the sewage distinctly pink to phenolphthalein (roughly 5 cc. per liter of sample). If volatile sulphide is also to be determined an additional sample must be collected. Aerate thoroughly to expel all volatile sulphide gas at time of collection, then add alkali as above.

Procedure:

A. Total Sulphide Sulphur.

Add 1 cc. of antimony solution (1) and a few crystals (about 0.5 gram) of sodium chloride (3) to a 4-ounce, clear glass bottle of the same quality as employed for the standards. Fill to 100 cc. with the water or sewage to be tested. A yellow color indicates the presence of sulphide. After mixing add 1 cc. of hydrochloric acid solution (2). Mix and compare with standards. Maximum color develops in ten minutes but for practical purposes readings may be taken immediately. The reading gives total sulphide sulphur (soluble in dilute HCl).

In sewage work a blank sample should be placed behind the standard to effect equal turbidities.

B. Non-Volatile Sulphide Sulphur.

If the sample has already been aerated at the point of collection proceed as under (*A*) recording the value obtained. Otherwise measure out roughly 150 cc. of the sample and aerate thoroughly to expel the volatile sulphides. Then proceed as under (*A*).

Calculations:

(*A*) P. p. m. total sulphide sulphur.

(*B*) P. p. m. non-volatile sulphide sulphur.

(*A-B*) P. p. m. volatile sulphide sulphur. For all practical purposes this value may be recorded as hydrogen sulphide (H_2S).

Notes:

1. Aeration of samples may be effectively accomplished by vigorous hand shaking in a closed jar or bottle. At intervals of roughly 25 shakes the container should be opened and the released gas blown out. Repeat this operation until no sulphide odor is noted when opening the container.
2. In the laboratory the aeration may be accomplished by drawing air through the sample at a rapid rate for 10 minutes.
3. Never add acid until antimony tartrate is mixed with sample.

4. If all volatile sulphides have been removed by aeration, little or no color is produced from antimony tartrate until after addition of acid.

5. The gelatine in the reagent (1) may congeal if the reagent is kept at 40° F. or below for a considerable length of time. Warming to redissolve the gelatine will restore its usefulness. The amount of gelatine in the reagent may be reduced to 7.5 grams per liter without affecting results. Below this amount some turbidity may develop in the treated samples.

6. The amount of dichromate reagent (4) required for each p. p. m. sulphide S in the standards was determined by comparing with known sulphide solutions with the eye. Possibly by using a colorimeter the amount could be more accurately determined.

II. The Iodine Method

Reagents:

1. Sodium thiosulphate—0.025 *N* solution (same as used in dissolved oxygen determinations).
2. Iodine—0.025 *N* solution (1 cc. equivalent to 0.4 mg. sulphide sulphur).
3. Hydrochloric acid—1 c. p. acid to 1 water.
4. Starch indicator—20 g. starch per liter.

Sampling:

Use the same procedure as suggested for sampling in connection with the antimony tartrate method for sulphide determination.

Portions of 200 cc. are preferred for titration. The cubic centimeters of *N*/40 iodine (2) consumed, multiplied, by the factor 2, equals the sulphide sulphur content in parts per million. If 100 cc. portions are titrated, *N*/80 iodine should be used.

Procedure:

Total Sulphide Sulphur.

A. Total iodine demand:

Measure out 200 cc. of sample into an Erlenmeyer flask, add 2 cc. dilute hydrochloric acid (3) and mix by *gentle* rotation. Add standard iodine solution (2) rapidly until excess is indicated by yellow color, stopper and shake closed flask to absorb any hydrogen sulphide that may have been released by the acid into the space above the liquid.

Add 1 cc. of *N*/40 thiosulphate solution (1) to discharge yellow color and then add starch indicator. If a blue color appears, add another cc. of thiosulphate to discharge the blue color. Return to the blue endpoint with iodine. From the total number of cc. of iodine added deduct the total volume of thiosulphate added. Record as number of cc. *N*/40 iodine demand of the sample.

B. Determination of blank:

Since substances other than hydrogen sulphide in the sample have an iodine demand, a "blank" determination is necessary.

Measure out another 200 cc. of sample. Proceed as under (*A*), except that the sample is thoroughly aerated *after* adding the 2 cc. of acid in order to expel the liberated hydrogen sulphide. The number of cc. of *N*/40 iodine consumed in (*A*) minus the number consumed in (*B*) multiplied by the factor 2 equals the total (volatile plus non-volatile) sulphide sulphur in p. p. m.

$$(A-B) \times 2 = \text{p. p. m. total sulphide sulphur.}$$

Volatile Sulphide Sulphur.

C. Iodine Demand after Aeration without Acidification:

If the sample has been aerated at the point of collection, measure out 200 cc. and proceed as under (*A*), recording the number of cc. of iodine solution required. Otherwise, measure out roughly 225 cc. of sample and aerate thoroughly to expel volatile sulphides. Add no acid to sample before aerating. With 200 cc. of the aerated sample proceed as under (*A*).

Calculations:

$(A-C) \times 2$ = p. p. m. volatile sulphide sulphur. For all practical purposes this value may be recorded as hydrogen sulphide (H_2S).

$(C-B) \times 2$ = p. p. m. non-volatile sulphide sulphur.

$(A-B) \times 2$ = p. p. m. total sulphide sulphur.

Notes:

1. Care must be exercised in collecting samples and in measuring them, so that loss of hydrogen sulphide will be prevented.

2. After acidification of the sample in the titration flask, handle gently and add iodine promptly.

Acknowledgment

The writer is indebted to Messrs. L. H. Enslow and Jack Hinman, Jr., for valuable suggestions, and to Mr. P. R. Welch, who assisted with the work.

Further Observations on Rapid Stage Sludge Digestion

BY A. M. BUSWELL* AND E. L. PEARSON**

In a recent paper[1] we described some changes occurring during an experiment on two-stage sludge digestion. The rapidity and high proportion of the digestion occurring in the first stage indicated that further study of this stage would be of considerable interest. In operating only the one stage and thus eliminating some of the sampling difficulties we also hoped to obtain a quantitative balance which would afford a clearer picture of the actual changes occurring during digestion than is now available.

The equipment used was essentially the same as that of the previous experiment, namely, a nidus sedimentation tank which provided three hours detention; and a digestion tank of 2300 gallons capacity, which, assuming a connected population load of 200, had a per capita capacity of 1.5 cubic feet.

This plant was operated as a digestion unit from September 24, 1929, to August 12, 1930. The digestion tank was seeded with 290 gallons of sludge from another tank and the remainder of the volume made up with tap water. Sludge from the sedimentation tank was added three times a day thereafter at an average of 21 gallons at a time. Artificial heating was employed to maintain the sludge temperature at slightly less than 25° C.

Sludge was drawn at the end of six weeks and again four weeks later. Thereafter it was drawn once every week for thirty-two weeks, then twice a week till the end of the experiment. An average of 190 gallons at a time was drawn during the weekly drawings, and 70 gallons at a time during the bi-weekly drawings.

The data given in Table I were direct determinations, except those for protein, which were calculated from the ammonia and total nitrogen determinations by the formula

$$6.25\ (\text{total nitrogen} - \text{ammonia}) = \text{protein}$$

It will be noted from the data that there was an apparent digestion of ash. After the experiment had been run for some time and sufficient data collected it became evident that there would be a loss of ash. The sampling technique was, therefore, investigated and it was found that the routine sampling method gave low results for both solids and ash on the digested sludge. The more gummy, gelatinous settling-tank sludge held in suspension heavy particles that could not be held by the digested sludge even while being vigorously stirred. Bottom samples showed as high as 20 per cent greater solids and ash than the regular random samples. A typical

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bottom sample on panning left a residue of 16 grams of solids, per liter of sample, which consisted chiefly of sand, gravel, small pieces of bones and seeds. Of this residue 54 per cent was non-volatile. A random sample taken at the same time left only 4 grams of solids per liter, of which 48 per cent was non-volatile. The total solids content of this sample was 6 per cent, or 60 grams per liter. The bottom sample, therefore, contained 12 grams, or 20 per cent more solids than the regular sample. Since the volume of this bottom layer of heavy solids was not known, a quantitative correction could be made on the basis of these samples. However, they do indicate that the sampling procedure introduced a consistent error in the solids determination of the digested sludge, resulting in a figure which is estimated to be low by 20 per cent. This estimate is further substantiated by the loss of 16 per cent of the ash as indicated by the data in Table I.

TABLE I

EFFECT OF RAPID STAGE DIGESTION OF SEWAGE SOLIDS

	Determined						Corrected		
	Total[b] Solids	Grease[c]	Protein[d]	Ammonia Compounds	Ash	Vol. Matter	Total Solids	Vol. Matter	Ash
Added lbs.	5942	1800	1066	42	1412	4530	5942	4530	1412
Residue lbs.	3360	335	550	213	1179	2181	3826	2414	1412
Digested lbs.	2582	1465	516	...	233	2349	2116	2116	0
Produced lbs.	..			171	...	..	..	..	..
Digested %	43	81	48	...	16	52	36	47	0

Gas Collected

	Per Cent	Cu. Ft.	Lbs.	
CH_4	63.4	25,180	1126	14.8 cu. ft. per lb. of solids digested
CO_2	31.3	12,430	1525	0.6 cu. ft. per capita per day (assuming 200)
H_2	1.6	635	4	8.4 cu. ft. per lb. of vol. matter added
N_2	3.7	....	..	6.4 cu. ft. per lb. of solids added
Total (CH_4, CO_2, H_2)		38,245	2655	

Corrected[a]

1.25 lb. per lb. vol. matter digested

18.1 cu. ft. per lb. vol. matter digested

[a] Corrected on the basis of error involved in sampling.

[b] Includes ammonium compounds (acetate and carbonate)

[c] Petroleum ether extract.

[d] Protein = 6.25 (total N − Amm. N)

With the equipment available a satisfactory sampling procedure adaptable to routine sampling on this scale of experimentation could not be developed. We therefore have adopted a smaller scale digestion unit (27 liters) to attempt to obtain a quantitative balance.

In the previous paper[1] on two-stage digestion, we reported that the

weight of "grease" digested corresponded to 56 per cent of the weight of gas produced. Neave and Buswell[2] have since found that because of the entrance of water into the reaction by which the higher fatty acids are converted into gas these produce more than their equivalent weight of gas. The amount can be determined by their formula for the homologous series of acids $(C_nH_{2n}O_2 + \frac{(n-2)}{2} H_2O = \frac{n+2}{4} CO_2 + \frac{(3n-2)}{4} CH_4)$ where n is the number of carbon atoms in the acid. The same authors[3] found that

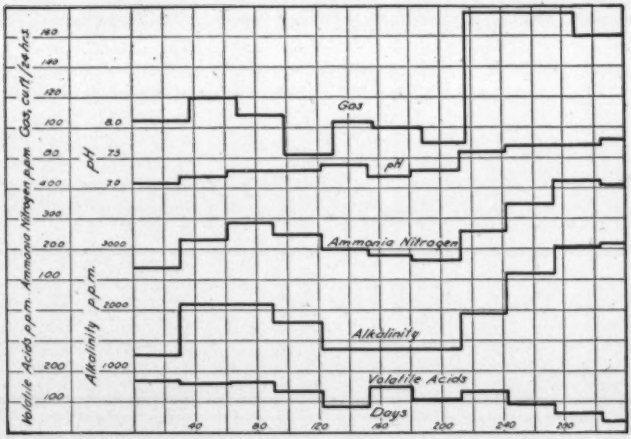

FIG. 1.—Rate of Gas Production and Variation in Ammonia Nitrogen, pH, Alkalinity and Volatile Acids in the Digestion Liquor. Sept., 1929, to Aug., 1930.—Rapid Stage Sludge Digestion, South Tank.

the "grease" in Champaign-Urbana sewage sludge was composed chiefly of a one-to-one mixture of lime soaps and unsaponified fats, the bulk of which were palmitic and stearic. On this basis the weight of grease digested in the previous experiment would correspond to considerably more than 56 per cent of the weight of gas produced, as reported, or approximately 75 per cent. On the same basis the weight of grease digested in the present experiment corresponded to 78 per cent of the total weight of gas produced, or 2070 pounds. In this calculation correction was made for the calcium in the saponified fraction but the glycerol fraction of the glycerides was neglected, since it becomes an insignificant fraction when the hydroxyl radicals replacing it are considered, and considering that glycerol itself produces some gas (as shown by Neave and Buswell[4]).

The next most significant material was protein, 516 pounds of which were shown to have digested, corresponding roughly to the weight (585 pounds) of the gas not accountable for by the digested grease.

There remained 600 pounds of solids which according to the data had been digested. The greatest part of this, however, as indicated by the tests on the sampling technique and by the apparent loss of ash, was not digested but lost in sampling. The remaining smaller fraction may be accounted for by dehydration and digestion of minor constituents of the sludge.

The "corrected" data in Table I were revised on the assumption that the ash indicated as having been digested was actually lost in sampling, as solids of a 50 per cent ash content, and is presented for comparison. The pounds of gas produced (1.25) per pound of volatile matter digested emphasize the error in considering the weight of gas produced a direct measure of the weight of volatile matter digested, and, therefore, a measure of the efficiency of digestion, as is sometimes done. For example, recovery of 95 pounds of gas from 100 pounds of added volatile matter does not mean that 95 per cent of the volatile matter digested to form gas. Seventy-six pounds of organic matter would give 95 pounds of gas.

The pH of the digesting material as shown in Figure 1 rose steadily from 7.1 at the beginning to 7.8 at the end of the experiment. It will be noted that the alkalinity, which is composed largely of ammonium carbonate, follows the trend of gas evolution. This suggests that possibly alkalinity and pH are the result rather than the cause of good digestion. The volatile acids follow a trend opposite to that of gas evolution. It is apparent that under proper mechanical conditions the process is self-regulating.

The digested sludge had an average ash content of 39.1 per cent, a solids content of 4.5 and a pH of 7.2. It had fair draining qualities and an inoffensive tarry odor. On a sand bed it dried to a moisture content of 65 per cent in 30 days, was gray in color and more fibrous in texture than sludge subjected to a longer digestion period.

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[2] *J. A. C. S.*, **52**, 3308 (1930).
[3] *Ind. Eng. Chem.*, **19**, 233 (1927).
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Some Operation Results, Los Angeles Sewage Reclamation Plant

BY R. F. GOUDEY*

On May 12, 1930, the Department of Water and Power, of the City of Los Angeles, under the direction of Mr. H. A. Van Norman, Chief Engineer and General Manager, and Dr. Carl Wilson, Director of Sanitation, placed in operation a complete sewage experimental plant having a capacity of 200,000 gallons per day. The purposes of this plant were to determine the installation and operation costs for different degrees of treatment meeting the requirements of various schemes of reclamation under investigation and to evolve the cheapest and best means for such treatments adapted to local conditions.

The experimental plant combines separate sludge digestion with gas collection, utilization and heating, together with the activated sludge process. One-third of the activated sludge effluent is given further treatment in a complete filtration plant including super-chlorination, coagulation, sedimentation, sludge return, filtration, dechlorination and wash water recovery. Complete operation records are kept and daily analyses are made of raw sewage, settled sewage, clarified activated sludge effluent, chlorinated and resettled effluent, filtered water and dechlorinated water. Tests are also made on fresh, activated and digested sludge. Weekly tests are made in the aeration and reaeration tanks showing changes in dissolved oxygen, free ammonia, nitrites and nitrates for various detention periods. All special research investigations are covered by appropriate tests.

The sewage arrives at the plant by gravity, in volume proportional to the flow in a 48-in. trunk sewer having an average discharge of 1.15 second feet. It contains various industrial wastes and arrives at the plant quite septic. The industrial wastes include: dye, salt and minerals from film laboratories, stearates from a soap factory, ground vegetable pulp from discarded vegetables from a dehydration plant, and cannery wastes from two large canneries. One cannery puts up pickles throughout the year, discharging a certain volume of brine with lactates. It also packs tomatoes from September to December, producing a heavy sludge; during the remainder of the year relish is made which results in heavy periodic discharge of green vinegar and turmeric. The second cannery handles peaches in July and August, producing a very heavy sludge and caustic water from the peeling machines. During the remainder of the year hominy is manufactured, which produces the heaviest sludge with the greatest oxygen demand values, as compared with other wastes.

The best indication of the type of sewage handled by the experimental

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plant is reflected in the table giving the performance of the preliminary clarifier. This sewage is roughly two to three times stronger than the average sewage from the entire city.

In the following discussion the findings should be considered as tentative only and as applying to local conditions.

1. **Preliminary Clarification.**—Experiments are being conducted on the percentage removals for various surface rates from 300 to 750 gallons

FIG. 1.—Los Angeles Experimental Plant. General View, Showing Aeration Tanks in Foreground, Blower House on Right, Filter Plant on Left and Digestion Tank in Background.

per square foot per day. The average detention period has been three hours with a rate of 430 gallons per square foot per day, giving 79 per cent removal of total suspended solids and 55 per cent removal of B. O. D.

Particular attention has been given to the type of sludge received. The sludge is pumped by a diaphragm pump, with an open discharge, in order that the consistency of the sludge may be inspected. It has been found that fresh sludge "bulks" just as does activated sludge, and, further, that when the pH of the raw sewage falls below 6.8 sedimentation is to a large extent defeated. This bulking and failure to settle is due in a large part to entrained carbon dioxide from fermentation and particularly to the presence of free carbonates. By adding lime to the raw sewage, to raise the pH value from as low as 6.5 up to 6.8 to 7.0, good sedimentation is secured. The amount of lime added is about twenty pounds per million gallons.

Lime, however, does not seem to concentrate sludge when the bulking agent is a derivative of the pectins in fruit wastes.

The following table gives the performance record of the preliminary clarifier:

CLARIFICATION

Average Monthly Results (Aug., 1930–Feb., 1931, incl.)

	Raw	Settled	% Removal
Total suspended solids	397	82.5	79
Volatile suspended solids	264	62.6	76
% volatile	66.5	76	..
Biochemical oxygen demand	440	200	55
Total organic N plus free NH_3	59.7	38.0	36.4
Alkalinity	274	255	7

The weight of dry solids removed is determined by two independent methods, the first depending upon the difference in suspended solids in the raw and settled sewage and the second upon the volume of sludge actually removed and its percentage of solids as determined from composite samples. The average pounds of dry solids settled per million gallons as determined by both methods is 2565 pounds. The first method gives results 4 per cent lower and the second procedure 3 per cent higher. The seasonal variation is from 2200 pounds to 3590 pounds per million gallons.

The fresh sludge has a water content varying from 88 to 96 per cent, averaging 94.35 per cent. The per cent of volatile suspended matter averages 67.7. Nitrogen content averages 3.3 per cent.

2. Excess Activated Sludge.—Many experiments have been conducted on the various methods of handling excess activated sludge, but so satisfactory is the system discovered in August of last year that no further work is being done on this line. It comprises the very simple expedient of pumping the excess activated sludge at a very low and uniform rate into the raw sewage ahead of the clarifier. There is a slight increase in the water content of the fresh sludge but the saving in volume of water pumped to the digester from any other method of handling far overbalances it.

Excess activated sludge averages 10,000 gallons per million gallons. Concentrating it by various method such as sedimentation, coagulation, chlorination, etc., reduces the volume to 3900 gallons per million gallons, with 97.8 per cent moisture, which is only 710 pounds of dry solids per million gallons.

It should be noted that the excess activated sludge has twice the volume of fresh sludge and contains less than one-third of the weight of solids. Even by concentrating the volume 2.5 times the amount of dry solids per gallon of concentrated activated sludge is 0.18 pound per gallon compared with 0.5 pound for fresh solids.

By returning excess activated sludge to the preliminary clarifier the

volume of fresh sludge pumped to the digester is increased from 5500 gallons per million gallons to about 6000 gallons total volume. Compare this with a total of 9400 gallons by using concentration methods or 15,000 by pumping direct to digester. The saving in overflow liquor from the digester amounts to 9000 gallons per million gallons treated, amounting to a 40 per cent improvement.

3. **Digester.**—The digester has a capacity of 37,500 gallons, giving an average detention period of only twenty-four days. The plant was designed on the basis of two cubic feet per capita. In spite of the exception-

FIG. 2.—Los Angeles Experimental Plant. Gas-Electric Generator and Electric Meters.

ally heavy industrial load fairly good digestion is secured. The sludge drains readily and is easily dried on natural sand beds.

At the start the tank was seeded with digested sludge, lime was added to control the pH and the temperature was maintained at 85° F. The tank at no time foamed but the sludge became overlimed at the bottom, producing a very strong ammonia smell when released.

Simultaneously with the pumping of sludge to the digester an equivalent volume of digested sludge is automatically released. This is stored in a tank until the volume is sufficient to fill a sand drying bed to a 12-in. depth. With fresh sludge entering at 94.35 per cent moisture and concentrated activated sludge at 96.5 per cent the digested sludge is discharged at 95.97 per cent. Overflow liquor is practically nil. By returning activated sludge to the clarifier this volume is still less. In fact the digester is allowed

periodically to stand quiescent overnight and clear water is withdrawn from mid-outlets in an effort to concentrate the sludge still further.

The digested sludge dries readily and is removed from the sand beds in ten days to two weeks. The nitrogen content is 3.5 per cent and 49.59 per cent of the solids are volatile. The production of sludge on the dry basis amounts to 1500 pounds per million gallons. About 965 pounds per million gallons represents weight of material gasified or liquefied.

The need of mixing excess activated with fresh sludge before pumping it to the digester is apparent. In fact, even with disposal of excess acti-

FIG. 3.—Los Angeles Experimental Plant. Stream-Line Paddles in Aeration Tank.

vated sludge into the raw sewage, there is still need of sludge circulation from bottom to top to prevent stratification and to hasten digestion.

Use of ferric chloride and celite as aids in sand drying of sludge cut the drying period from ten days to two days. Mechanical filtration with vacuum equipment indicates that digested sludge can be filtered to 72 per cent water. The cost of chemicals for either sand drying or mechanical filtration is $3.50 per million gallons of sewage treated. For less concentrated sewage the cost would be reduced in proportion to the dry weight of solids.

Gas production averages 2500 cubic feet per day or 26 cubic feet per 1000 gallons of sewage treated. It is equivalent to 1.25 cubic feet per capita. Experiments on utilization of this gas have not been completed. There is sufficient gas produced to operate generators to run the entire plant. One

kilowatt is produced from 40 cubic feet of gas, which is equivalent to 36 horsepower per million gallons. The gas has the following analysis: Gross B. t. u., 721; net B. t. u., 689; sp. gr. 773; carbon dioxide 12 per cent; marsh gas 68.5 per cent; oxygen 2 per cent; and nitrogen and air 17.5 per cent.

The cooling water on the gas-electric generator when used is more than ample to heat the digester. In fact, cold water has to be mixed with it.

4. Aeration.—Aeration tanks are 10 ft. deep. Detention periods average 5.5 hours for the settled sewage with return sludge and 4 hours for sludge, although this has been varied from 1 to 9 hours for the former and 0 to 12 hours for the latter. Sludge in the aeration tanks, measured volumetrically, has varied from 5 to 98 per cent and in the sludge reaeration from 0 to 99 per cent. Total solids in the aeration tanks, as measured by monthly averages, have varied from 1000 to 3300 parts per million. The ratio of weight over volume of solids, expressed as percentages, varies from 0.15 to 1.7.

Curiously the best effluent, namely, one in which the squeegee plates in the bottom of the final clarifier are visible, is when the sludge is semi-bulked. For good aeration and good nitrification it has been found advisable to keep the percentage of sludge by volume between 10 and 20 per cent, the sludge in the reaeration tank at 70 per cent or lower, the total solids in the aeration tank between 1000 and 2000 parts per million and the sludge ratio (weight/volume) between 0.5 and 1.5.

Sludge has been bulked from five causes. The first is from peach and tomato wastes carrying carbon dioxide. Lime, when added promptly, overcomes this difficulty. The second cause is over-reaeration of sludge or under-aeration of sewage and sludge, which will cause 100 per cent bulking before lime will be of any help. The third cause is high bacterial count in sludge, but what the proper limits are for the total count in sludge or aeration tanks has not been determined. Chlorination of returned sludge when this condition prevails helps greatly. The fourth difficulty is due to mineral oil or grease, in which case neither addition of lime nor increase of air assists. Only washing and dilution with final effluent, 30 per cent by volume, repeated three times, reduces bulk 50 per cent. The fifth cause is the periodic discharge of caustic wastes from peach, tomato and hominy plants and other carbonate wastes, which lime immediately corrects. The difficulty is probably not the causticity but the pectins and sugars contained in these wastes.

For three months all bulking at the plant has been controlled by returning clear water from the last clarifier to the aeration and reaeration tanks and carrying a low percentage of sludge in the reaeration tank. When observation indicates that the preliminary clarifier sludge is starting to bulk lime is occasionally added to the reaeration tank. A bad case of bulking

takes several days to develop and by use of lime and returned clear water it is easily controlled before it reaches the fully bulked stage.

The return of clear water to the aeration tanks, 15 per cent by volume, greatly improves the treatment. The only explanation is that of enzyme action. Further work along this line is being conducted. Another expedient to reduce bulking of sludge is to by-pass a small volume of settled sewage into the returned sludge before reaeration. A crude explanation is that the depleted sludge needs new food material to develop organisms which will make a better sludge.

A very useful measure of the rate of purification in the aeration tanks is the collection of samples at various points and allowing them to settle thirty minutes. The clear water is analyzed for dissolved oxygen, free ammonia, nitrites and nitrates. A study of these relationships will be made public in the near future.

The volume of air applied for all purposes varies from 0.17 to 0.5 cubic feet per gallon, averaging 0.45 cubic feet per gallon. Paddles of the Imhoff type, revolving at 5 r. p. m., require 3.1 horsepower, of which 1.8 horsepower is lost by friction in a speed reducer which could drive a unit of 5 times the capacity. The power requirements for a million gallon plant would be 8.3 horsepower for paddles and 7 for air, or a total of about 15 horsepower.

The air distribution produced by the motion of the paddles is uniform, prolonged and in every respect satisfactory. It is well adapted for low horsepower requirements. The sewage in question would probably require much more air per gallon were it not for the paddles.

It is hoped that preliminary treatment at the canneries will produce a sewage more nearly normal so that even lower rates of air consumption can be tried out.

The purification produced by the aeration process is given in the table on the following page. The activated sludge contains 99.45 per cent water, 70.11 per cent volatile suspended matter and 3.77 per cent nitrogen.

5. Final Clarification.—First final clarification is on the basis of 1.4 hours detention and a settling rate of 900 gallons per square foot per day.

The second final clarifier gives 2¼-hour detention and a settling rate of 550 gallons per square foot per day.

The question is immediately raised—why settle twice? The answer is—to give flexibility to the plant, provide a factor of safety in case of necessity, to provide detention for chlorination and keep the tank free of sludge, and finally to remove solids passed by the first clarifier.

The following table gives the performance of the activated-sludge process and includes average results for all experiments, good and bad:

ACTIVATED SLUDGE PROCESS
Settled Sewage to Final Effluent
Average Monthly Results (Aug., 1930–Feb., 1931, incl.)

	Settled	Effluent	% Improvement Change	Based on Raw
Total suspended solids	82.5	10.6	87	97.5
Volatile	62.6	8.0	87	97.0
% volatile	76	75	..	..
B. O. D.	200	4.78	98	99
Total N + NH_3	38.0	8.43	78	86
Nitrites	...	3.96	..	..
Nitrates	...	7.27	..	..
D. O.	...	3.35	..	..
Oxygen consumed	...	9.72	..	..
Turbidity	...	8.9	..	..
Alkalinity	255	200	21.5	27

The improvement produced in the second clarifier over the first in final sedimentation is given in the following table.

EFFECT OF DOUBLE SEDIMENTATION

	1st Clarifier	2nd Clarifier	% Improvement
Total suspended solids	14.8	10.6	28
Volatile suspended solids	12.7	8.0	37
% volatile	86	75	..
B. O. D.	5.85	4.78	18
D. O.	2.26	3.35	33
Total N + NH_3	7.97	8.43	6
Nitrites	4.12	3.96	4
Nitrates	7.62	7.27	5
Oxygen consumed	10.4	9.72	6.5
Turbidity	11.1	8.9	19.9
Alkalinity	206	200	3.5

These results certainly justify the installation of double sedimentation.

Further Treatment

Operation results of the complete water purification plant filtering a portion of the activated sludge effluent together with results of water spreading, travel of underground pollution, character of recovered water and experiments on the value of digested sludge for fertilizer would make too long a discussion for this present article. Some very interesting work is being done with ferric chloride as a coagulant and in the regeneration of activated carbon with hypochlorites.

The final water is clear, clean, odorless, tasteless and suitable for drinking purposes. The average daily analyses since the plant operated, including all experiments in continuous daily runs, are given in the following table.

FINAL EFFLUENT
Filtered

Average Results (Aug., 1930–Feb., 1931, incl.)

Total suspended solids	0
B. O. D.	1.2
Total N + NH_3	5.3
Nitrite plus nitrate	11.2
D. O.	3.1
Oxygen consumed	5.3
Alkalinity	173
Turbidity	0.5
Chloride	127
pH	6.9

The Action of the Activated Sludge Process on Sewage Bacteriophage. A. D. STEWART and S. C. GHOSAL. *Indian J. Med. Research*, 1930, **17**, 1215. A detailed account is given of experiments made to determine whether bacteriophage originally present in the sewage increases in activity during the activated sludge process, causing rapid diminution of bacteria or, if not, what becomes of it. The investigations were carried out at an experimental activated sludge plant with an air-lift aeration system at Hooghly Jute Mill, a Simplex activated sludge plant in a mill area near Calcutta and in the laboratory, using aspiration apparatus for aeration. *B. coli.*, *B. shiga* and *B. flexner* were used. The experimental results indicated that: (1) the germicidal action in the activated sludge process is not due to enhanced activity of sewage bacteriophage; (2) the activated sludge process has a definite destructive action on sewage bacteriophage; (3) no consistent diminution of phage occurs before 6 hours aeration, thus differing from germicidal action, which is progressively active from the first hour; (4) reduction of phage is approximately 90 per cent, after 6 hours aeration, although some resistant strains are unaffected, and nearly 100 per cent, after 24 hours aeration. Many strains of phage are completely destroyed.—Abs. No. **216**, *British Summary of Current Literature, Water Pollution Research*, Vol. IV, 2 (February, 1931).

Sewage Works Operation

Handling and Disposal of Screenings*

By Frank L. Flood**

The offensive character of sewage screenings makes their prompt removal and final disposal desirable. Racks and screens when operated without regard to the production of odors may create seriously objectionable conditions. The provision of adequate means for handling and disposal of screenings has not until recently received attention commensurate with the problems involved. Too often these problems have been passed on to the plant operator with the recommendation that the screenings be buried, burned or otherwise disposed of in a sanitary manner. A noble-sounding phrase but rather an indefinite tool to place in the hands of the operator.

It is true that in the case of the small installation with a small production of screenings, and where there is land available they can be buried in trenches, plowed under or merely covered to prevent odors, the problem of disposal is not serious except, possibly, as regards fly and rodent breeding. As the volume increases and land becomes more restricted the problems of handling and disposal become more difficult until the point is reached where adequate provision should be made in the design of the treatment plant for handling the screenings with facility and for their satisfactory disposal.

Character and Quantity of Screenings.—In general, the character and quantity of screenings depend largely upon whether the sewers are on the separate or combined system, on the character of the people or industries served, on the season of the year and on the disintegration of the sewage solids in the system prior to screening. For any particular plant they depend especially on the size of opening in the rack or screen and on the frequency and method of cleaning. Screenings consist of paper, feces, garbage and rags with occasionally large quantities of twigs and leaves, depending on the season. They weigh 40 to 60 lb. per cu. ft. and contain 80 to 90 per cent moisture. The volatile matter on dry basis is 80 to 90 per cent.

The quantity of screenings removed by bar racks ranges from 0.5 to 2.0 cu. ft. per mg. of sewage treated although rates as high as 6 cu. ft. per million gallons have been removed by fine racks of $^1/_2$-in. clear spacing.

* *Presented before the New England Sewage Works Assoc., October 15, 1930.*

** *Asst. Eng., Metcalf & Eddy, Boston, Mass.*

TABLE I

QUANTITY AND CHARACTER OF SCREENINGS

Location	Type of Screen	Opening, Inches	Screenings: Per Mil. Gal. Cu. Ft.	Screenings: Lb. per Cu. Ft.	Screenings: Per cent Moisture	Per cent Volatile Matter in Solids—Dry Basis
Fine Screens						
1 Pasadena, Cal.	Dorrco	1/16	12.5	.. ..	87.74	84.51
2 Milwaukee, Wisc.	Link-Belt	2/32	...	308 ..	91.91	...
	Reinsch Wurl	5/64	8.8	.. ..	82	83
3 Brooklyn, N. Y.	Reinsch Wurl	1/16	7.5	.. ..	80	81
(26th ward)	Reinsch Wurl	3/64	5.7	.. ..	86.8	93.5
	Reinsch Wurl	1/32	5.2	.. ..	77	68
4 Los Angeles, Cal.	Dorrco	1/16	16.5	.. ..	87	...
5 Long Beach, Cal.	Dorrco	1/32	27	1810 67	87	...
6 Long Beach, Cal. (1925)	Dorrco	1/16	29.8	1850 62	87	...
7 New York, N. Y.	Reinsch Wurl	3/64	27.1	1449 53.4	78	88
(Dyckman St., 1919)	Reinsch Wurl	1/16	18.4	1040 56.5	82	91
8 Rochester, N. Y. (1928)	Reinsch Wurl	1/8	6.2	394 59.8	92	...
9 New Britain, Conn. (1922)	Dorrco	1/16	18.8	1069 56.9	80	...
10 New York, N. Y. (1926)	Rex	3/64	...	2180 ..	92	88
11 Pleasantville, N. S. (1926)	Link-Belt	1/32	32.6	.. ..	...	...
Racks						
12 Toronto, Ont.	Inclined	2	0.30	15 50	...	...
13 Plainfield, N. J. (1912)	Inclined	0.5	5.7	261 46	84	...
14 Worcester, Mass. (1928)	Inclined	2.0	1.80	121 67	...	...
15 Boston, Mass. (1927)						
So. Met.	Cage	1.0	4.74	.. ..	...	...
No. Met.	Cage	1.0	1.70	.. ..	...	...
16 Washington, D. C.		1.5	0.63	37 54	...	...
17 Atlanta, Ga.		1.625	...	40 ..	...	...

(1) Year ended June 30, 1930 (2) 10 mos. ending Oct. 31, 1929
(6) Remodeled plant (10) Canal ft.
(12) No. Toronto Plant 1st 6 mos.

The quantity removed by fine screens varies considerably, quantities between 5 and 30 cu. ft. per mg. being not unusual. Data on the character and quantity of screenings from a number of plants are given in Table I.

Handling Screenings.—Where racks are cleaned by hand, the screen-

ings may be taken up with broom and shovel and loaded on wheelbarrows, or they may be shoveled into industrial cars for disposal at the sludge dump. Where racks are machine cleaned, screenings are either discharged directly into receptacles or conveyed to them by band or screw conveyors. Fine screens are usually provided with containers into which the screenings are swept or delivered by bucket conveyors, or they are equipped with bands on which the screenings are transported to receptacles. The screenings accumulating in the containers are, in some cases, ejected by compressed air into carts or cars which carry them to the point of disposal, or if screenings are treated or disposed of in the plant or its immediate vicinity, the compressed air may convey them through pipes to the point of treatment or disposal.

Disposal Methods.—The prevailing methods of disposal include (1) burying or plowing under, (2) fill, (3) incineration and (4) disposal at sea. Screenings are sometimes compressed to remove some of their moisture, reduce their bulk and facilitate disposal, particularly in conjunction with incineration.

Burying.—Screenings should not be buried too deeply, as they will decompose but slowly if removed from the upper layers of the earth (known as the zone of "living earth") in which bacterial activity is greatest. Appleton[1] reports that: "In excavating for the foundation of a new incinerator at Long Beach, Cal., screenings buried 27 mos. before were uncovered. These had been placed in pits about 4 × 12 ft. in plan and 8 ft. deep, a few feet above high tide line, and were covered with about 2 ft. of sand. For the first 2 ft. these screenings were comparatively dry and gave off a mild odor. Matches, hair, rags, paper, etc., were plainly visible and the print on pieces of newspaper was easily decipherable. Underneath was a soggy mass, in appearance similar to pig muck, but with a much worse odor."

However, screenings should be covered sufficiently well to prevent odors and fly breeding. At Plainfield, N. J., screenings are spread upon neighboring farm lands and plowed under. At Rochester and Syracuse, the fine screenings are carried to a dump and, to avoid nuisance, covered with the material removed from the grit chambers.

Dewatering.—Prior to disposal and particularly where the method of disposal is by incineration, screenings are sometimes dewatered to reduce their weight and bulk.

There are two methods of dewatering: (1) by pressing and (2) by centrifuging. Screenings from racks have been pressed at a number of plants for many years. The presses have usually been of the "cider" type, operated by steam or hydraulic pressure. Screenings at Dayton are dewatered in a press made by the Hydraulic Press Manufacturing Company (Figure 1). The press basket consists of a steel slab curb 28 in.

in diameter and 30 in. deep. The hydraulic press has 100 tons pressure capacity making the pressure on the screenings 325 lb. per sq. in. It takes about 20 min. to make one pressing. At this rate the capacity of the press is about 250 cu. ft. wet screenings for 8 hours operation. A press of this size costs, installed, about $2500 and weighs about 4200 pounds.

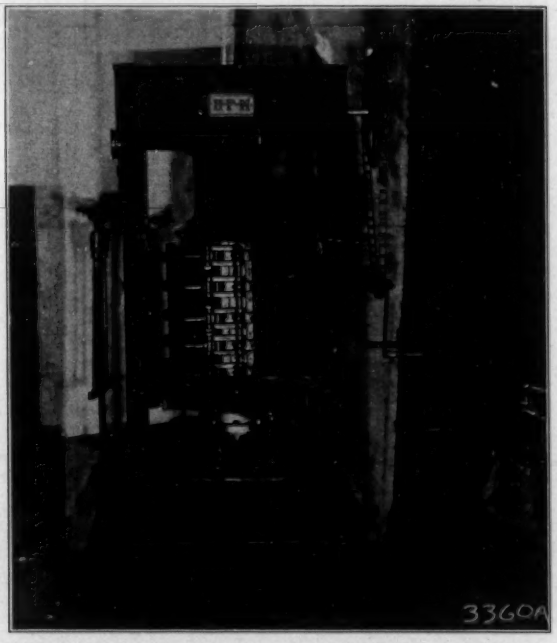

FIG. 1.—Press for Dewatering Screenings (Hydraulic Press Mfg. Co.).

The screenings are reduced about 50 per cent in volume and after pressing contain about 65 per cent moisture and 35 per cent solids of which about 4 per cent is ash.

At Allentown, Pa., during the first six months of 1930, 11.5 cu. ft. of screenings per day were reduced to 6.4 cu. ft. per day by dewatering in an hydraulic press similar to that at Dayton. The average reduction by pressing was 45 per cent.

At Baltimore during a test run, unpressed screenings averaging 7.75 cu. ft. per mg. of sewage weighing 60.17 lb. per cu. ft. and containing 86.45 per cent moisture were reduced by presses to 4.04 cu. ft. per mg., weighing 50.03 lb. per cu. ft. and containing 72.19 per cent moisture.

The screenings at the Ward Street pumping station in Boston are dewatered to 65–75 per cent moisture.

Kenneth Allen[2] stated:

"Normal screenings, whether from racks or fine screens, may be dewatered in a press of proper design to such an extent as to be disposed of by burning under boilers, in a garbage incinerator or in an incinerator especially designed for the purpose, with little additional fuel."

It is probable that screenings may be dewatered by centrifuge although this method has been used to a limited extent only. At Reading, Pa., screenings from a fine-mesh "Weand" screen were placed in canvas bags and dewatered by a centrifugal "hydro-extractor" about 6 ft. in diameter by 3.5 ft. high, which reduced a charge of 500 lb. from 85–90 per cent to 61–73 per cent moisture in 8 minutes. Its weight was reduced from 65–70 lb. to 30–35 lb. per cu. ft. by the process. The dewatered screenings were burned under the boilers at the plant. The screen was abandoned in 1912.

Experiments were conducted by George G. Gascoigne at Cleveland, in which about $1^1/_4$ tons of fine screenings, 85% moisture, after a brief period of draining were placed in a "Laundryette" centrifuge. The moisture was reduced to 65% and the screenings burned in a small "Kewanee" incinerator by adding about 25 per cent of coal by weight.

Experiments are now being carried on at Milwaukee with a 48-in. special wringer type of centrifuge as made by the Tolhurst Machine Works. Preliminary results indicate that the machine has a capacity for about 500 lb. of bar rakings or 800 lb. of fine screenings per charge, with three charges per hour at rapid operating conditions. The per cent moisture of the material is reduced from about 90 to from 65 to 70. The cost of the machine installed was about $3750.

Incineration.—Where steam boilers are operated at the plant, screenings are often burned under the boilers after draining or pressing. This is done at some of the Boston cage screening plants. Where high-temperature refuse incinerators are controlled by the municipality, it may be practicable to convey the drained or compressed screenings to the incineration plant for disposal.

At Long Beach, Cal., the screenings are burned in an incinerator constructed at the fine-screen plant.[3] During the fiscal year ended June 30, 1926, a total of 80,220 cu. ft. of screenings weighing 2507 tons was burned. The ash removed weighed 29 tons and was used for filling in around the plant site. The moisture content of the wet screenings was from 85 to

88 per cent. It required 105.8 cu. ft. of natural gas at 1150 B. t. u. per cu. ft. to incinerate 1 cu. ft. of wet screenings. The cost of incineration per ton of wet screenings was $1.29, of which $0.69 was for fuel, allowing 20 cents per 1000 cu. ft. for gas secured without charge from the municipal gas plant.

At Dayton, Ohio, pressed screenings containing about 65 per cent moisture and 35 per cent solids are burned in an incinerator and reduced about 95 per cent in weight. The incinerator is fired by gas collected from the Imhoff tanks and stored in pressure tanks underground. The gas required to burn the screenings during September, 1930, was about 4.0 cu. ft. per lb. of pressed screenings incinerated.

A pressing and incineration plant for screenings, similar to that at Dayton, is provided at Allentown, Pennsylvania. The cost of the incinerator at Allentown was about $3000 and of the stack, exclusive of foundation, $1700. This plant has not as yet been operated continuously.

During a test run on the incineration of screenings at Baltimore, Md.,[4] an average of 11.07 lb. of bituminous coal was required to burn 1 cu. ft. of pressed screenings containing 72.19 per cent moisture and weighing 50 pounds.

About 0.2 lb. of coal was required at Washington, D. C., to incinerate 1 lb. of pressed screenings containing 85 per cent moisture.

Pressed screenings containing 69 per cent moisture and weighing 52 lb. per cu. ft. are burned in small oil burning "incinerites" at three plants in the vicinity of Flushing Bay, Borough of Queens, N. Y. Screenings weighing 145 lb. were consumed in 3 hours with a loss of 93 per cent in weight. About 0.018 gal. of oil was burned per lb. of pressed screenings incinerated.

During experiments by Gascoigne at Cleveland, dewatered screenings containing 65 per cent moisture were burned with the addition of about 25 per cent by weight of coal.

To prevent odors from the stack, it is desirable to maintain temperature in the incinerator above a minimum of 1250° F. Average temperatures of 1600° F. are provided at Dayton. Of 8760 temperature readings taken inside the combustion chamber at the Long Beach incinerator, the highest was 1690° F. and the lowest 1561° F. Satisfactory results have been obtained with these temperatures.

A comparison of the fuel requirements for the incineration of screenings may be obtained from the data in Table II. Apparently from 2000 to 3500 B. t. u. are required to incinerate 1 lb. of screenings.

Digestion of Screenings.—Large-scale experiments in digestion of fine screenings alone were made at the Milwaukee sewage treatment plant.[5] The screenings added contained an average of 91.5 per cent moisture and about 90 per cent volatile solids. The digested material

drawn contained 93.75 per cent moisture and 53 per cent volatile solids. The temperature in the tank averaged 84° F. Gas production averaged 5.7 cu. ft. per lb. dry solids treated. The heating value was about 400 B. t. u. per cu. ft. of gas produced. With a tank capacity of 6750 cu. ft. an average of 3400 lb. or about 55 cu. ft. per day of wet screenings was

TABLE II

COMPARISON OF FUEL REQUIREMENTS FOR THE INCINERATION OF SCREENINGS

Location	Per cent Moisture in Screenings	Fuel Required to Burn 1 Lb. of Screenings	Assumed B. t. u. per Unit of Fuel	Estimated B. t. u. Required per Lb. of Screenings Burned
Long Beach, Cal.	85.88	1.7 cu. ft. gas	1,150	1940
Dayton, O.	65	4.0 cu. ft. gas	700	2800
Baltimore, Md.	72.19	0.22 lb. coal	14,000	3080
Washington, D. C.	85	0.20 lb. coal	14,000	2800
Cleveland, O.	65	0.25 lb. coal	14,000	3500
New York, N. Y.	69	0.13 lb. oil	19,000	2470

treated. This is equivalent to providing 123 cu. ft. of tank capacity for each cu. ft. per day of wet screenings requiring disposal. The digested material was intensely black and drained readily on underdrained sand beds. Difficulties in operation, consisting mainly of the formation of a thick, heavy blanket of floating material, were said to be overcome by the installation of a scum saturator. The practical results at Milwaukee were on the whole disappointing and plans for a pressing and incineration plant are under preparation.

Experiments on the digestion of mixtures of screenings and activated sludge indicated that, while properly seeded activated sludge digested alone at 70° F. in 30 days, 10 and 20 per cent replacement by screenings increased the digestion period to 35 to 40 days, respectively.

Screenings may also be digested with ordinary sewage sludge. At Baltimore, Md.,[4] where fine racks are employed to protect pumping equipment, a series of tests was conducted during the period from June to October, 1926, on the grinding of sewage screenings in a "macerator." After being ground, the material was returned to the sewage. A 24-in. by 18-in. macerator, costing about $600, was capable of shredding from 1.5 to 2 tons of screenings per hour with a current consumption of about $^1/_4$ kw.-hr. per cu. ft. of ground material. The tests indicated that the macerator would grind screenings satisfactorily and, according to Keefer, that under certain conditions the cost of this method, including digestion and drying on sludge beds, would compare favorably with the cost of pressing and incinerating them. Keefer[6] further reported as follows:

"The experimental work on the pulverizing of sewage screenings was concluded in October, 1926. Immediately thereafter the machine was

permanently installed at the Eastern Avenue Sewage Pumping Station, Baltimore, Md., and since then has been used to grind all the screenings collected at this station. The quantity of material pulverized varies from 200 to 300 cu. ft. per day.

"The machine now (April, 1930) has been in successful service for approximately 3½ years. It has been necessary to install one set of hammers in the grinder since the machine was purchased; other than this, practically no repairs have been required. The grinder pulverizes practically everything that is present in sewage. However, in pulverizing rags it is necessary to introduce the material into the machine at a slow rate.

"The grinder has proved its worth to the extent that plans are being prepared to install two machines for grinding screenings caught on coarse bars at the Baltimore Sewage Works."

At sewage treatment works, where it is desired to remove as much coarse material as possible, partly to lighten the load on subsequent treatment units, the adding of macerated screenings to the sewage would defeat the purpose for which the screens were intended. The possibility of increasing the scum on sedimentation and digestion tanks requires consideration.

Disposal at Sea.—At New York City, the screenings from the existing fine screening plants are carried on a barge to sea and dumped with the garbage. This method carries with it the danger of material being washed upon the shore under certain conditions of wind and tide unless the dumping grounds are well out to sea or otherwise properly located.

Conclusions

Experiments and plant scale operation have demonstrated that sewage screenings may be successfully treated and disposed of without nuisance. Although burying of the untreated screenings may be satisfactory for small plants with a reasonable degree of isolation and adequate available areas, some form of treatment prior to disposal may be required for larger plants or for small plants not advantageously located for raw screenings disposal. Incineration is the most complete treatment. The screenings are reduced to an inoffensive ash which is about 1.0 to 2.0 per cent of the original volume of screenings. Pressing the screenings prior to incineration, in order to reduce the moisture content from about 90 to about 65 per cent, is advantageous. Disposal by digestion, either alone or in conjunction with other sewage solids, appears to be still in the experimental stage. The method of treatment and disposal best suited to any particular plant will depend on local conditions and requirements.

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[5] C. E. Keefer, "Pulverizing of Sewage Screenings at Baltimore, Maryland," *Proc. A. S. C. E.*, **55**, 1759 (Sept., 1929).

[6] W. Rudolfs and H. M. Heisig, "Gas Production from Screenings at Milwaukee, Wisconsin," THIS JOURNAL, **1**, 519 (Oct., 1929).

[7] C. E. Keefer, "Pulverizing of Sewage Screenings at Baltimore, Maryland," "Discussion," *Proc. A. S. C. E.*, **56**, 1021 (May, 1930).

Sewage Screening in California. *The Third Annual Journal of the California Sewage Works Association*, recently issued, contains several articles describing the disposal of screenings at Salinas, Long Beach, Ventura and Pasadena.

The Salinas plant includes a separate screening plant and settling tanks for cannery wastes. The Dorrco screen is covered with 20-mesh monel metal fabric. Wastes are discharged from the canning of peaches, tomatoes and pears. Screenings and sludge are hauled to the city garbage dump.

The Dorr screens at Long Beach have slots $^1/_{16}$ inch wide by 2 inches long. Screenings are blown from the pneumatic ejector to a covered measuring hopper above incinerators, which take a charge of approximately 3000 pounds every 4 hours. At present about 9 tons of screenings are being handled per day in 6 charges. The average flow is 10 m. g. d. Gas is used for fuel, at the rate of 1.5 cubic feet (1200 B. t. u.) per pound of screenings, containing 90 to 92 per cent moisture.

Screenings at Ventura are spread on sand to a depth of 6 inches. They dry in 3 days sufficiently to be hauled away.

Sewage at Pasadena is screened through $^1/_{16}$ by 2-inch slots. Screenings amount to only 95 cubic feet per day from 7 to 8 m. g. d. of sewage. At present these screenings are buried in ditches. It is proposed to substitute pre-settling for screening if it is found to be feasible to incorporate the settled sludge with the activated sludge.

The report containing these papers may be obtained from the Secretary, E. A. Reinke, 3093 Life Sciences Building, Berkeley. Abstracts or reprints will appear in the next issue of THIS JOURNAL.

Imhoff Tank Sludge as Farm Fertilizer Canton, Ohio, Sewage Works*

BY CHAS. C. HOMMON**

The disposal of sewage sludge in a satisfactory and economical manner is well recognized by the sanitary engineering profession as being one of the most difficult problems in the treatment of municipal sewage. The manner in which this phase of sewage treatment has been handled at Canton, Ohio, for the past few years is a radical departure from commonly accepted American practice and should be of interest to the sanitary engineering profession because of its simplicity and practicability.

The Canton Sewage Works is of the Imhoff-tank, trickling-filter type and was designed for a population of 135,000 persons. It is estimated that approximately 100,000 persons are now contributory to the plant. It is located about eight miles south of the city on what is locally known as the municipal farm, which is operated as a part of the sewage works under the management of the plant superintendent. The farm comprises nearly 600 acres of quite rolling land, 200 acres of which are either wooded or too rough to permit of economical cultivation. Located on this acreage at advantageous points are three residences and barns, around which all agricultural activities of the enterprise are centered. Three city employees live in the three residences and work mainly on the farm and care for the city-owned live stock and farming implements. All farm products are sold at the best market price, the money being turned into the general fund of the City of Canton. The common crops raised are wheat, corn, oats, hay and potatoes.

As previously stated, the farm is operated as a part of the sewage treatment program for the express purpose of providing a means of disposing of the sewage sludge.

The sewage plant is located near the middle and at the extreme western side of the farm, along the bank of Nimishillen Creek, a small stream into which the plant effluent is discharged. The sludge pumping equipment, for transferring the wet sludge as drawn from the sludge wells of the Imhoff settling tanks to the farm land, consists of two triplex 10 in. by 10-in. plunger pumps, powered by 40-hp., 220-volt motors, and approximately 5500 feet of 6-in. force line. Each pump has a capacity of 300 gal. per min. when operating at 30 revolutions per minute. The force line lies about midway between the north and south boundary line of the city's property and terminates on the top of a knoll which is approximately 300 feet above the surrounding territory. From this high point the sludge

* *Delivered before North Carolina Sewage Works Association, Hendersonville, North Carolina, October 14, 1930.*

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flows in open ditches following the contours, to acreage as far as two miles. The ditches are formed usually by means of an ordinary farm breaking plow. The force line is also provided with suitable connections, 6- by 6- by 3-in. tees, at points where it is desired to distribute sludge from time to time.

At the time of pumping sludge on to the ground, three men are required for proper distribution. The spreading of the sludge is accomplished in the simplest manner, by keeping the open ditches at the highest elevations possible and allowing the ditch to overflow at proper intervals to cover the desired area. If all of the sludge is flowing in one ditch, there are usually three points of overflow, each man caring for approximately one-third of the flow. Due to the sloping topography of most of the area,

FIG. 1.—Main Sludge Channel and a Lateral, Canton Municipal Farm.

it is possible for the laborers to follow down the slopes in front of the sludge and, so to speak, to fan it out by miniature ditches and dikes and in this way cover relatively large areas from one point of discharge. Many observations have been made to determine the best condition of spreading the wet sludge. It appears that there are but few choices, the most difficult condition being excessive slopes on hard, dry ground, devoid of any vegetation. Under these conditions it is difficult to retain the sludge within limited areas. Any appreciable amount of vegetation, however, retards the flowing sludge to a remarkable degree and renders it possible to cover satisfactorily relatively steep slopes. Likewise, snow during the winter months assists materially in spreading the sludge by retarding the flow. On ground that is relatively poor, or areas which it is desired to sludge heavily, it is best to plow before treatment. The plowing not only loosens the ground, which permits of ready absorption of the con-

tained water, but the small pockets formed on the surface by the plowing afford ideal catchment areas for the sludge. In the way of an experiment, a part of the 1930 fall wheat crop was planted and then covered with sludge. The results appear to be very satisfactory. The wheat in the sludge areas is much in advance of that in the unsludged areas. The same general scheme was tried with the 1930 corn crop. The dry weather was seriously interfering with the growth of corn; wet sludge was applied to the ground about the time when the ears were being formed. When harvesting the crop, it was quite noticeable that the area on which the wet sludge was placed yielded not only a larger quantity, but a better grade of corn. On numerous occasions the value of the sludge as a fer-

FIG. 2.—A Plowed Field Being Covered with Sewage Sludge from the Canton Sewage Works.

tilizer for grass has been well demonstrated, not only in a small way on lawns but also on meadows, the hay from which was used as stock feed.

To use sludge properly one should know something about the food requirements of the respective crops, the character of the soil and also something of the character of the sludge. For instance, it is well recognized that clover requires an alkaline soil, whereas most sewage sludges are inclined to be slightly acid. It therefore follows that sludge is not a complete fertilizer for such a crop and requires the addition of sufficient lime to develop the proper reaction. Likewise, in the fertilization of oats with sewage sludge, one must apply the sludge sparingly, otherwise the growth becomes excessive and the crop is most likely to fall down before or soon after heading and thus complicate harvesting of the grain.

The length of time such a scheme, as above described, could be employed for disposing of sewage sludge from approximately 100,000 persons on

the limited area available was somewhat of a speculation in the early history of the plant, but experience has shown that for best results the acreage should be re-fertilized about every four or five years. This repetition, and the desire of abutting property owners for sludge for enriching their acreage, created by observing the results obtained on the municipal farm, has provided what now appears to be unlimited areas. In one instance a farmer owning property adjacent to the city's farm purchased a small centrifugal pump, which he operated with a Ford tractor, and sufficient pipe to transfer the sludge across a valley to his acreage. He is well pleased with his investment, the only disappointment being that the city cannot supply him with sufficient sludge. As further indication as to how the agriculturists in the immediate vicinity of the plant feel regarding the use of sewage sludge in a wet form as a fertilizer, it may be stated that a number of farmers owning property some distance from the plant are now considering pooling their interests with a view toward securing sufficient capital to purchase the necessary equipment for delivery of sludge to their acreage.

The scheme of sludge disposal as employed at Canton greatly facilitates the operation of the sewage treatment works. It is believed that most all sewage plant superintendents have experienced uncomfortable intervals, by not being able to move sludge from the settling tanks when desired. It is well known that sludge digestion does go wrong at times, causing serious difficulties in the proper operation of the sedimentation devices. The one sure remedy for relief is removal of sludge from the tanks. Such sludge is always difficult to handle on drying beds because of the high organic content and inability to dry it in a reasonable time. Such emergencies are easily met when the sludge is being disposed of as at Canton. If the sludge is poorly digested and likely to give trouble from obnoxious odors, it is always possible to flow it over areas sufficiently far removed from habitation so as not to give rise to complaints. In this connection, it should be mentioned that in many instances sludge has been distributed over quite large areas that were close to residential properties and public highways, and that no complaints from odors have come to the writer's attention. One probable explanation of the absence from odors is that the soil readily absorbs the contained water, thus quickly leaving the sludge in a dry condition. On a number of occasions land has been rather heavily sludged one day and cultivated the following day. Another feature of the scheme that appeals to the writer is that sludges of low water content—a condition sometimes difficult to accomplish but desirable where the sludge is to be handled on drying beds—are of but little or no advantage where the sludge has to be pumped. As a matter of fact, a sludge that contains more than 6 per cent solids is difficult to handle through a force line because of the excessive friction loss. This phase of

the problem at Canton requires some watching because of the long force line and the excessive elevation to which the sludge is raised. There have been times when it was necessary to thin some of the heavier sludges either with water or with a more liquid sludge.

The division of costs of operation of the Canton Sewage Works does not permit of detailed accurate analysis to illustrate the merits of the scheme from an economical view-point. Rough estimates indicate, however, that the cost of placing the wet sludge on the farming acreage is no greater, and perhaps less, than the cost of removing the sludge from drying beds. Other items of expenditure, such as costs of constructing sludge drying beds and necessary appurtenances, maintenance, depreciation and interest on investment, are believed to be much in favor of the scheme as employed at Canton. Sufficient net revenue is derived from the sale of farm products to more than pay the interest on the purchase price of the land. Another item that is significant, and one that is hard to estimate, is the increased value of the property due to the general building up of the soil.

No doubt sewage sludges vary greatly in their fertilizing value and will react differently when applied to various soils and crops, but the writer's experience, not only in Canton but elsewhere, has strongly indicated a general strengthening of the soil.

It is not the desire of the writer to place another burden on the shoulders of the sewage plant operator by suggesting that he become a farmer, as it is believed that he now has ample duties; but it would be unfair to say that the operation of the municipal farm has been anything other than a pleasure. Perhaps one thing that makes it a pleasure is the fact that an otherwise useless product is being turned back to nature and again placed in useful channels.

The Separation, Digestion and Disposal of Sewage Solids*

BY JOHN R. DOWNES**

The question of digestion of sewage sludge cannot be considered without giving due consideration to the inter-related subjects of collection of the solids and the final disposal of the sludge.

For instance, it frequently happens that in a battery of Imhoff tanks operated in parallel there will be a great deal of difference in the quality of the sludge obtained from the various tanks, as well as in the difficulties of keeping the tanks in good condition, although they all apparently receive the same raw sewage from a common source.

As a matter of fact, they are not all receiving the same sewage, but each is receiving a fractional, but not necessarily equivalent, part from a common source. If this source be an open channel with side outlets to the tanks, even though the volume of liquid may be most carefully apportioned among the tanks, the weight and character of the solid material reaching the various tanks will vary widely. The reason for this is that even at the scouring velocities which we seek to maintain in such channels there is a distinct separation of solids, the heavier solids being dragged along the bottom while the greasy material floats on the surface. Since the pressure is greater at the bottom of the channel than at the top, it is the bottom material containing the heaviest solids, which is forced out via the first available opening.

The resulting sludge in the first tank will tend to be dense and granular while that of the last tank will be thinner and pasty and slow drying.

With this difference in sludges produced in the same plant from the same sewage it is apparent that sludges from different plants and from different sewages must be compared with the greatest caution. That a given type of digestion tank will produce a dense sludge at one place is no criterion that the same type of tank will produce equivalent sludge at another place or that a type of tank that produces thin sludge at one place will fail to produce dense sludge at another.

Obviously, sludge from separate sewage systems, cannot be compared with sludge from combined systems, nor sludges from tanks preceded by grit chambers or screens with sludges from tanks with no preliminary treatment apparatus.

A pertinent observation which, if given due consideration, may save much operating expense as well as much installation expense, is that the sludge from settling tanks preceded by grit chambers will be much more

* *Delivered before North Carolina Sewage Works Association, Hendersonville, N. C., October 14, 1930.*

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mobile, requiring less effort to move it and permitting of much shallower hopper construction. It is true that the sludge from the tank preceded by a grit chamber will be less dense, but if density is gained merely by adding grit to the sludge, of what value is that density?

A great deal of importance has been attached to the production of dense sludge. Barring the case of sludge which is dense simply because it contains grit, dense sludge has the advantage of lesser volume to be transferred to the drying beds or mechanism and in the case of the drying beds, it has been held that less sludge bed area will be required, but little attention has been given to the relative cost of holding sludge in digestion tanks until it is dense, and of treating a less dense sludge on a larger bed area.

With reference to a given sludge, time alone is the factor which produces denseness. With modern, high-speed controlled digestion we can get a well digested sludge inside of 40 days but it will not be as dense as sludge which has laid for some 120 days in a large digestion tank.

This statement may have to be amended as thermophilic digestion is developed further. Present indications are that the high temperature digestion may produce a dense sludge in a comparatively short time.

Solids from an inefficient settling tank will give a more dense and a more easily drained sludge than solids from an efficient settling tank, not only because there will be a smaller volume of sludge to digest, but also because the solids which escape an inefficient settling tank are those which would tend to produce a pasty sludge, difficult to handle, and in the case of Imhoff tanks, would tend to produce foaming.

In the case of sludge digested in Imhoff tanks, success or failure of digestion may depend to as great an extent on the design of the settling compartment as on the design of the digestion compartment. This is because a design of settling compartment which will permit the piling up of green solids at one point, instead of distributing them more or less evenly over the entire surface of the old sludge, is not conducive to proper seeding and will permit of the development of acid fermentation inside the large masses of settled solids, where seeding is not effective because the solids pile up faster than the seeding organisms can penetrate the mass.

It was stated above that it has been held that less sludge drying bed area will be required to dry a given weight of dry solids in the form of dense sludge than would be the case for the same weight of dry solids in the form of a thin sludge.

An eight per cent sludge, for instance, will contain twice as much actual solid matter per 100 cubic feet as will a four per cent sludge, and it has been assumed that only one-half the bed area would be required for the eight per cent sludge, in order to provide for the drying of all the solids from any given plant. This assumption is a fallacy, as may be readily shown by a little thought and observation.

By mixing sludge of 7.8 per cent solids, obtained from the bottom of a controlled separate-digestion tank, with sludge of 2.0 per cent solid content, obtained at a higher elevation in the same tank, the writer produced sludges of varying densities and allowed them to stand for observation in tall glass cylinders. Both sludges were equally well digested, each containing 47 per cent ash, a pH of 7.6 and had all other indications of well digested material.

From the 2 per cent sludge clear liquid separated very rapidly at the bottom, separation beginning immediately and being complete; that is, having reached the ultimate separation, inside of six hours. From the heaviest sludge appreciable separation began only after a period of 48 hours. The ultimate quantity of liquid separated from the sludges of various densities was inversely proportional to the densities.

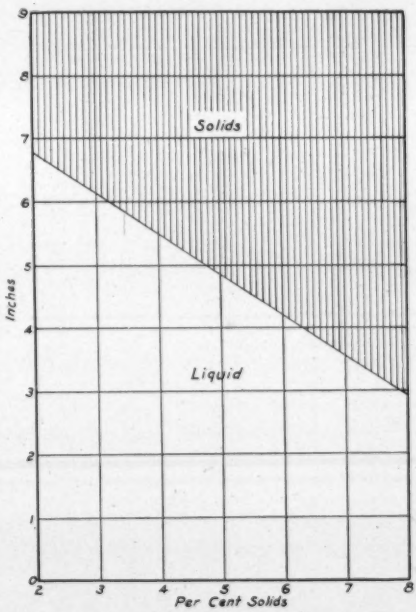


FIG. 1.—Depth of Liquid Separating from Sludge of Various Densities, in 9-Inch Column.

The drying of sludge on sand beds may be divided into two stages, drainage and evaporation. Drainage is practically limited to the first 24 hours, since, by the end of that period, solid material from the under side of the floating sludge begins to fall down and seal off the sand.

The second portion of the drying process, evaporation, has been observed to proceed at the rate of approximately one-half inch of depth per day in a $4^1/_2$-inch depth under the most favorable conditions, after the initial separation of water has taken place. A 5-inch thickness of sludge would become spadable in 11 days, and a 4-inch thickness in 6 days. Below

4 inches the time would be shortened much more rapidly. From 4 to 6 inches is the practical working range.

Figure 1 indicates the ultimate separation of liquid in depth corresponding to a 9-inch depth of sludge applied to the bed. The chart was prepared from observation of the depth of the liquid separating from sludge in tall glass cylinders 4 inches in diameter.

The heaviest sludge in the series, with solids of 7.8 per cent, yielded

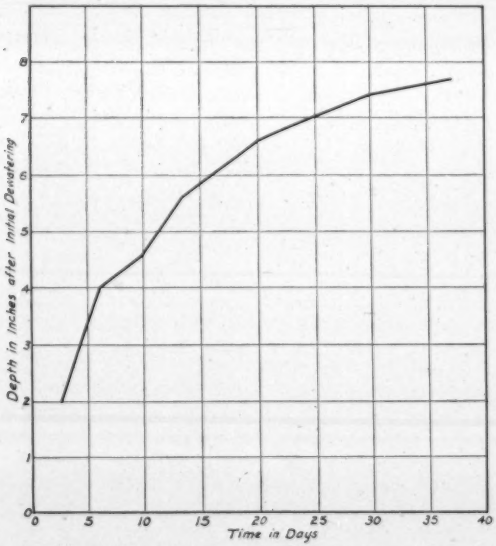


FIG. 2.—Days Required to Dry Sludge by Evaporation.

only 3 inches of water after 48 hours, leaving at least 6 inches of sludge to be dried by the slow process of evaporation. I say "at least 6 inches" because it took 48 hours to separate this 3 inches of water and it is probable that after the first 24 hours the sand surface would be so sealed off as to retard or prevent the drainage of all the liquid.

The thinnest sludge tested, containing 2 per cent solids, yielded the ultimate depth of liquid within 6 hours and before sludge solids began to settle, so that all of the water would have drained off very rapidly.

The intermediate dilution, containing 3.9 per cent solids, yielded 5.5 inches of liquid, leaving 3.5 inches of sludge to be dried by evaporation.

Referring to Figure 2, which shows the number of days required to dry different depths of sludge after the first liquid has been drained off, we note that there is a peculiar break in the curve between a depth of 4 and $4^1/_2$ inches, in which there is notable slowing down; between $5^1/_2$ and $6^1/_2$ inches the loss in time of drying is not so great; above $6^1/_2$ inches the time lengthens rapidly. Now using the data in both charts we find the following:

% Solids in Sludge	Loss by Draining	Depth to Dry by Evaporation	Time Required for Drying, Days
4	5.5	3.5	1 + 5 6
5	4.8	4.2	1 + 7.5 8.5
6	4.2	4.8	1 + 11 12
7	3.5	5.5	1 + 13 14
8	2.9	6.1	1 + 17 18

This comparison indicates that 6 per cent sludge takes twice as long to dry as does 4 per cent sludge and, therefore, at this point the advantage of the denser sludge vanishes, while 8% sludge will take 3 times as long to dry as will the 4 per cent, though it contains but twice the weight of fresh solids. There still remains with the denser sludge the advantage of thicker cake to be removed from the bed, making for less effort in gathering a load for the cart or truck, and one preparation of the bed instead of two, to remove the same weight of dry solids. On the other hand, should a dose of the dense sludge be rained on during the first 24 to 48 hours, the drying time would be lengthened indefinitely and tie up the area for a time out of all proportion to the thickness of the dose. Also remember that there is no assurance that all of the liquid would drain off from the heavy sludge on account of the long time, 48 hours, required for the ultimate initial separation.

Just to illustrate how important a proper depth of sludge is, let us compare depths of 8, 9 and 10 inches.

DAYS REQUIRED TO DRY DIFFERENT DEPTHS OF SLUDGE OF VARYING SOLID CONTENTS

% Solids	8 in. Depth	9 in. Depth	10 in. Depth
4	$5^1/_2$	6	6
5	$6^1/_2$	$8^1/_2$	10
6	9	12	13
7	12	14	16
8	14	18	23

These figures will not hold for all sludges or for all sand beds, but the relations will be in about the same proportions.

Unfortunately, the writer has not had available for experiment any concentrated sludges, but he believes that the relative separation of liquid would hold good up to a 12 per cent solid sludge, at which point the separation becomes zero. This checks with the experience of many operators

that 12 per cent solids is the dividing line between sloppy and stiff sludges or scums.

According to these observations it would seem that we could not afford to construct large digestion or storage tanks merely for the purpose of getting a dense sludge. This is particularly true since the time and, therefore, the size of the storage tank required to secure the denser sludges are fully 3 times as great as that required to secure well-digested sludge.

We might recapitulate the accepted essentials of successful sludge digestion as follows:

1. Get the settled solids to the digesters as quickly and in as fresh a condition as possible.
2. Feed the digesters with fresh solids systematically and uniformly.
3. Keep the heat uniform or rising evenly up to 82° F.
4. If there is any delay in getting the solids to the digesters, correct the acidity with lime.
5. If it is necessary to add an unusually large dose of green solids, add lime with the solids.
6. Keep the digesters well filled with old ripe sludge, drawing only enough to make room for the incoming dose.
7. If you have more than one digester unit, use all of them all of the time, giving each its share of the daily dose of green solids.

Preservation of Metal Surfaces above and below Sewage Surfaces*

BY R. S. RANKIN**

The preservation of metals around a sewage plant has for its main object the protection of metal structures against corrosive agents, including the atmosphere, sewage, trade wastes and the like. These metals may generally be classed as those above the level of the sewage and those below, or immersed in the sewage. As a rule, cast iron, by its very structural nature, is not subject to serious corrosion, so that our discussion will be confined solely to steel structures, with the conclusion that preservative methods applicable to steel will be equally or more suitable for cast iron.

We all know that atmospheric oxygen is the universal corrosive agent. Whether it is free, as in the air, or dissolved in the water or sewage, oxygen must be kept from the metal, if true preservation is desired. Other agents of corrosion most commonly encountered in sewage treatment plants are hydrogen sulphide and its attendant compounds, chlorine and acid trade wastes. Hydrogen sulphide is not usually present in many plants in quantities sufficient to cause trouble, but where it has occurred, special studies and precautions have been taken. Chlorine corrosion is usually not serious where care and attention are given to chlorinating equipment and methods of applying the gas to the sewage. Acid trade wastes are seldom present in sewage in quantities sufficient to produce a resulting acid solution, and where they do occur, the waste should be neutralized before reaching the sewage plant.

Abrasion of metals may also be classed as an agent of destruction, as it truly is, but preservation of metals against this source of trouble is mainly one of mechanical and plant design, and, therefore, will not be included.

Paints are most generally used to preserve metals against corrosion and these may be roughly divided according to their base into five classes, so far as common practice is concerned. These are: graphite, coal tar, asphalt, red lead and metal emulsion paints. All of these have been used with varying degrees of success. There are about as many different opinions as to what constitutes the best paint as there are paint manufacturers. Not only is the paint base, but also the pigment vehicle, a subject of much debate.

Black paints formerly seemed to be the universal color for most finished work, but recently other colors, which have been used successfully, have created a demand, as it were, for more cheerful colors. This is due largely to the development of the metal emulsion paints, of which aluminum is the

* *Round Table Discussion, New York State Sewage Works Association, September 13, 1930.*

** *Sanitary Engineer, The Dorr Company.*

most widely used base. The desire for pleasing colors has been partly instrumental in developing two classes of paints for finished work, one for visible, or above-the-sewage-level structures, and the other for structures out of sight, or below the level of the sewage.

What constitutes the perfect paint for these conditions? Any answer must, of course, be qualified, because so many factors enter into it, and we might start an endless debate; but, in order to get something concrete before you, our experience would lead us to use the following: For the shop coat, red lead in linseed oil with drier; first field coat, same as shop coat; second and third field coats (*a*) above water, aluminum emulsion paints, and (*b*) below water, any good asphalt base paint. This makes four coats in all, and where this has been used, no evidence of deterioration has been noticed. Tests of long duration have not been made with this combination, but we do know that anything less is not always an adequate protection for all conditions. Each coat requires care in selection of materials, mixing and in application; but with four coats of carefully applied paint, any imperfections in one coat are taken care of by the others.

Red lead as a base shop coat seems to have no equal, and if the red lead itself can be protected by subsequent coats, even hydrogen sulphide will not attack it. Aluminum paint presents an excellent appearance, but care in mixing is required to insure a smooth, workable film. As a preservative against the elements, it also appears excellent.

Asphalt-base paints are generally easily applied, while some coal-tar paints require heating for best results, an accomplishment oftentimes difficult of proper attainment. Coal-tar paints also contract, if applied in heavy coats, leaving check marks, while asphalt paints are not so likely to do so. Graphite paints give good protection above water.

In our experience with sewage digester mechanisms, it may be interesting to note that at one plant there was practically no evidence of corrosion after two years of operation, even though the initial painting job was very poor. Absence of oxygen and organic acids doubtless explains this result.

In other equipment below water, painting or touching up every two to three years is recommended, although here again no serious corrosion has been noted in plants operating for five years without attention. Above water, evidences of corrosion should be checked by painting as required, the same as for any structures.

At the present time we are conducting some exhaustive tests on various protective paints, but since time is the only sure test, these have not been going on long enough to produce definite results. Tests of this character are needed to establish some fundamental basis for determining the most suitable protective or preservative paints.

Discussion

Following the reading of this paper by Mr. Rankin, Mr. Wm. A. Ryan, Rochester, N. Y., stated that Headley's emulsified road tar is an effective coating for concrete. Brown asphalt paint is used at Rochester to coat metal exposed to sewage.

C. C. Agar, Albany, N. Y., stated that the corrosion at the flow line was more intense due to the repeated wetting and drying of metal at this point.

Professor Henry N. Ogden, Ithaca, N. Y., stated that red lead paint did not adhere to a galvanized iron roof. It was later pointed out, however, that new galvanized iron is coated with a film of oil or grease which prevents the paint adhering. If the galvanized roof is painted, after the iron has been exposed to the weather and the grease film removed, the paint will adhere.

Mr. William Gyatt, Syracuse, N. Y., stated that red lead mixed with linseed oil adheres satisfactorily to metal surfaces.

Mr. L. H. Enslow, Chlorine Institute, New York City, stated that road Tarvia diluted with benzine has been used at the Grand Rapids sewage pumping station with complete success. Mr. Enslow indicated that the hydrogen-ion concentration at the metal surface controlled corrosion, and that sulphur compounds in the sewage were the most important corrosive agents. Hydrogen sulphide fumes are very corrosive to switchboards and exposed copper in pumping stations. Mr. Ryan replied to this latter statement by saying that copper may be protected by a special lacquer developed by the General Electric Company. Mr. Enslow inquired whether titanium base paint has been used by anyone present. No reply was received.

Mr. Wm. R. Eckhart, Rochester, N. Y., stated that cider vinegar may be used as a cleansing agent before applying protective compounds to metal surfaces.

Mr. John F. Skinner, Rochester, N. Y., stated that serious corrosion of steel pipe used in Rochester was due to the electrical potential on the two surfaces of the pipe which in turn is due to the existence of dissolved oxygen of the water inside of the pipe and carbon dioxide in the ground water surrounding the pipe. Mr. Skinner pointed out that red lead is very heavy and difficult to apply and that painters were likely to neglect thorough brushing of the paint. It was also stated that the Superior Graphite Paint, consisting of red lead, graphite and linseed oil, was a very effective protective coating. This paint is manufactured by the Detroit Gas Company.

Discussion—Sewage Plant Operators' Problems Iowa Sewage Treatment Conference, Iowa State College, Ames, Nov. 12–14, 1930

Chairman—LINDON J. MURPHY

One of the most valuable parts of these conferences is the discussion that follows a paper. The discussion this afternoon is to cover the general subject of sewage treatment. This may not be entirely new to some of you who have been here before, but I think you will appreciate this review of how the plant functions and what makes the bugs work. The fundamentals of sewage disposal will be covered this afternoon.

Discussion—Separate Sludge Digestion vs. Imhoff Tanks

An engineer recently mentioned the fact that many cities and villages were putting in separate sludge-digestion tanks in their new sewage treatment plants. He also said that he thought separate sludge digestion had superseded the old Imhoff tank. Any new invention in sewage treatment seems to be the ultimate treatment and we more or less discard the others. Another engineer thinks that the Imhoff tank fills the needs of some towns very well. I have suggested to Mr. Wieters and Mr. Currie that they tell you someting pro or con on this subject of whether or not we should throw away the Imhoff tank.

Mr. Wieters: I realize that this is a very controversial subject and I am going to be very careful in what I say in connection with it. I have one distinct advantage, because just before this meeting I was talking with Mr. Currie and I asked him if he thought separate sludge digestion had superseded Imhoff tanks, and he said that he did not think it had.

I am simply going to try to point out some of the advantages of the one type over the other. The proponents of the clarifier advocate it because they say there is less interference with septic action. But I think there is very little difference in the two. You can design an Imhoff tank that will give practically the same conditions. There is one disadvantage to the clarifier. You have a moving mechanical arm which constantly agitates the sludge and this may bring back into solution some of the material already settled out. In some clarifiers this has been noticed and in some it has not. In some instances the matter has been taken care of by slowing down the motion of the mechanical arm.

In separate sludge digestion you have complete separation of the settling and digestion chambers, but it seems to me that the advantage of this is a matter of opinion. In the Imhoff tank, there is always the possibility that the stale liquid that lies above the digesting sludge will have free access to and mix with the fresh material that is coming down into the settling com-

partment. Other factors, such as temperature currents, can cause the tendency to mix.

One of the principal talking points for separate sludge digestion is flexibility of control. If lime is necessary in order to adjust the pH, it is much more easily applied than in the Imhoff tank. However, some of the later types of clarifiers have been designed without the mechanical mixing arm but have pumps for mixing the fresh sludge with the digesting sludge. It seems to me that this could be done as easily in an Imhoff tank as in a separate digester.

One of the arguments used for the separate digester and the mechanical equipment is that it will require the attention of an operator, and that the operator will have to be there to look after the equipment. That might be more justly an argument against it. It does require more attention than an Imhoff tank, for you have more mechanical moving parts. The separate sludge-digestion plants have not been in operation long enough for us to know how expensive they will be to maintain and operate, nor how frequently they will need to be replaced.

Most separate sludge-digestion plants now being built are equipped with units for collecting gas and heating the sludge, thus getting more complete digestion and getting it in a shorter time. This is also possible with the Imhoff tank. On a recent trip through Texas I saw several plants that were using this with the Imhoff tanks. In this connection, so far as digestion is concerned, the Imhoff tank has one decided advantage over separate digestion where the units are not heated. The Imhoff tank is built entirely below ground, and as a result of that and the layer of water on the top, it keeps comparatively warm without heating. The temperatures will probably maintain a higher level in an Imhoff tank than in a separate digestion tank when not heated. In the separate digestion tank there is very little heat from the fresh sewage that is coming in.

In the separate digestion tank we get away from foaming. There is probably a lot to be learned about foaming, but I notice that is one of the subjects for the round table discussion on Saturday. It occurs to me that in the later designs of the Imhoff tanks they are making provisions to take care of the scum and foaming. I always remember the remark of Mr. Bufkin from Mason City at one of these conferences. He was asked what he did when his tank foamed, and he replied that he let her foam. If it does not overflow into the flowing-through chamber, that is a pretty good solution.

For cities of from ten to twelve thousand population there is not much difference in the cost of installation of the Imhoff tank and the separate sludge digestion, but for cities of from three to five thousand population Imhoff tanks have been found somewhat cheaper. It seems to me that that is still quite an important factor here in Iowa. It might be possible

to sell a sewage disposal plant to a city for from thirty-five to forty thousand dollars, but to add six or ten thousand dollars to the price would kill the whole proposition. In regard to operating costs, Mr. Currie will tell you something about that.

Mr. Currie: The Imhoff tank has disadvantages that the separate clarifier and sludge digestion do not have. Some communities have wastes that develop acidity and need control, such as an overly large amount of creamery waste in the smaller towns. It is more difficult and more expensive to treat acidity in the Imhoff tank than in the separate sludge-digestion tank where you have merely the sludge itself to consider. The temperature of the digestion tank is very important, and may be the cause of foaming. The tank may be located in a place where the ground conditions maintain a low temperature throughout the year. But there are many communities where the Imhoff tank fills the needs of the community very well. I would go even further and say that I do not believe that septic tanks are entirely obsolete, when the cost of construction is a serious item, and where the location of the tank is sufficiently isolated from the homes.

The difference in operating costs between the Imhoff tank and the separate digestion tank varies a good deal with the relative size of the two. Some small Imhoff tanks are doing well with less operating attention than the mechanical clarifiers. But when you get into the larger sized plants the argument might be in favor of the mechanical clarifier, and would certainly be in favor of it in regard to pleasure of operating it. You can't get as intensive digestion, nor can you handle some kinds of waste in an Imhoff tank that you can in a separate digestion tank. To say that any method of sewage treatment is entirely obsolete is going pretty far. I think there is a place for the sand filter, the trickling filter, the activated sludge plant, the septic tank and the Imhoff tank. There is a place somewhere in which every one of these will be justified as the proper method of sewage treatment.

Mr. Murphy: I think Mr. Wieters and Mr. Currie have mentioned some very good points, and I wonder if any of you men would like to take issue with them. What experience have you men had with these two types of plants? Theoretically, one may be good here and another there, but what do you find your experience to be?

Mr. Witter: The Imhoff tank that we have at Newell was built so it sticks out of the ground about fourteen feet and we found that we had to bank it up. We have never had any trouble except that the gas vents fill up. We don't know what foaming means.

Operator: How about the odor, do you have any?

Mr. Witter: We do have a little odor, but we have no flies.

Mr. Bragstad, Sioux Falls: I am inclined to agree with Mr. Currie. From my observation, none of the types mentioned are ready to be dis-

carded. Every city and village presents a problem by itself that justifies one type of tank rather than another. We have had a separate sludge-digestion plant in operation for three years. It is a fairly large plant and was originally designed for gas collection and heating. The heating equipment was not installed at first, and as the plant was put into operation in the fall, there was some delay in seeding and getting digestion. We are taking a large percentage of packing house waste.

Chairman: Don't you get milk products waste, too?

Mr. Bragstad: Relatively a small amount. The packing house waste is the largest factor. We get two-thirds packing house waste and only one-third domestic sewage. The sludge capacity is rather large for the city. The plant was originally designed for gas collection and heating the tanks. This feature was added just about when the contract was let. It was installed without the gas-collection unit. The plant was placed in operation in the fall, with no seeding of the tanks. The plant went through the winter with no apparent activity, storing up raw sludge. There was a little gas, but not much. When the temperatures began to rise in the spring the activity began, and the foaming began in May, and there was some scum formation.

Tests were run regularly on the pH and lime was added almost daily. From 150 pounds to 300 pounds per day were added in an attempt to adjust the pH of the sludge. We thought we could stop the foaming in that way. During the summer we frequently called in men from outside, men who were experienced in the operation of these tanks, and they suggested ways to stop the foaming. We succeeded in keeping the pH around 6.6 and sometimes bringing it up to 7 by the addition of lime. The foaming did not stop permanently. It would stop for a while and then begin again. We tried circulating the sludge. We drew the sludge and pumped the tanks. The circulation of the sludge seemed to aggravate the foaming at times. The temperature went from 48° to 70° F. for a short period, then it came down to 60° F.

The tanks were not overloaded. All the time the sludge was accumulating and in the fall we had from three to four feet of scum on the top of the tank. We went into the winter without much improvement in the operation of the tanks. During the winter we installed the heating coils, and the following spring the heating apparatus was placed in operation. As soon as we got the temperature of the sludge to 70° or above, the pH came up and has been running 7.2 to 7.4 ever since, and the foaming has ceased.

Only a relatively small amount of scum forms. I think during the first year of operation we did not succeed in getting alkaline digestion that we should have, and that we lacked the proper sort of organisms. This demonstrates the importance of temperature in proper sludge digestion. In plants in this latitude the temperature control is of extreme importance.

This plant was not provided with facilities for the removal of scum from the top of the tank.

Operator: What did you do with the scum?

Mr. Bragstad: We ran the scum out on the sludge beds. There have probably been many of you who have had experience with foaming. I don't see how we could have gotten along without the temperature control. We had foaming no matter what other methods we used.

Mr. Stull, Storm Lake: We had some trouble getting the right pH at our plant. We added 50 to 75 pounds of lime and got a pH of 6.6 to 6.8. Then we added 250 pounds of lime at a time, and the pH improved considerably. I now add 200 pounds of lime for every 4000 city population. I think one of the troubles in adding lime is that we do not add enough.

Operator: How about your temperatures?

Mr. Stull: The temperature runs from 62° to 68° F.

Foaming

Mr. Murphy: The City of Boone has had a similar experience with foaming in the Imhoff tanks. Mr. Nelson, can you tell us something about the operation of the plant at Boone?

Mr. Nelson: We have not had any foaming for a year now. I don't know whether we are just lucky or if we have done something that has stopped it.

Mr. Murphy: Have you figured out what caused the foaming there at one time?

Mr. Nelson: I can't say that we have arrived at an explanation of the foaming. Our experience was similar to that at the Sioux Falls plant. Our plant consists of two Imhoff tanks, and the plant was put in operation in February when the temperature was about zero. There was no sign of gas in the tanks for about two months. Then it gradually started and it was not long before the tanks were foaming. We had trouble for about a year, and added lime in two or three different ways. We collected the effluent from the filter and pumped it back into the tank. We made a solution of milk of lime and pumped that into the tanks, then we applied milk of lime to the sludge in the tanks, a barrel to each tank. That seemed to have as much effect as anything we have used. The foaming subsided but we had more or less trouble for a year. We tried chlorine but did not have a very good method of applying it. We used about 12 parts per million but that did not seem to help the foaming. We have not had any trouble for a year now.

Mr. Murphy: Putting an open tank in operation in the middle of the winter does create a problem of getting a good seeding.

Mr. Boyce: Practically every new sewage tank has some trouble with foaming the first year. When the sludge starts to digest there is likely to

be some foaming. It helps if the plant has a large enough capacity so that it is possible to keep some of the digested sludge in the plant for seeding. Removal of too much sludge makes the foaming recur. If you keep some of the digested sludge with the other sludge it will minimize this difficulty.

Operator: How much should you keep?

Mr. Boyce: Keep as much of the active sludge as you can.

Mr. Bufkin: I understand that some have more trouble with foaming in the winter than in the summer. My experience has been that the colder the weather the less foaming there is. At zero there is practically no foaming, but in hot weather it is practically impossible to control the foaming.

Mr. Murphy: At every plant of which we have a record, serious foaming has come during the warmer weather. Hence your experience, Mr. Bufkin, would seem to agree rather than run counter to that of others.

Mr. Drake: What would you do with a plant that keeps foaming and foaming but digests nothing, and smells bad?

Mr. Currie: Is it a new plant?

Mr. Drake: About the fourth season for it.

Mr. Pickens: It is difficult to understand why a tank that is four or five years old should not become properly balanced.

Mr. Drake: The water in the tank is black, and the gas brings the scum and sludge to the top and we can't make it settle.

Mr. Pickens: Is the discharged sludge tarry in color and odor?

Mr. Drake: The sludge turns green, and if it runs a little while it becomes just sewage-like.

Mr. Mark: I know the layout of that particular plant. Has the creamery been disconnected?

Mr. Drake: No.

Mr. Currie: The water in that territory is very high in sulphate.

Mr. Drake: We have changed the water supply recently, but it is in the same location and probably contains the same material. The sludge is drawn off three times a year, the fall, spring and summer. A lot of raw sewage rises to the surface of the flowing-through chamber.

Mr. Currie: You had better examine your tank and see if you have an Imhoff tank at all. I am not saying that this is your trouble, but about twelve years ago in a city I know of, the city engineer made the design for a sewage treatment tank. The contract was let to a local contractor who was not very well versed in the interpretation of engineers' designs. The plant was built but never worked properly. The covers for the tank were to be plank, but the contractor proceeded to put a concrete cover over the Imhoff tank. The engineer had designed lugs across the bottom, but the contractor and inspector had misinterpreted these lugs for openings. So the space of the lugs was closed and the rest was open, so there were only

two or three twelve-inch openings for the sewage to settle through. I am not suggesting that this is your trouble, but there may be something wrong with the construction of your tank.

Mr. Drake: About two years ago the engineer recommended that we divide the tank with a board partition that goes clear through from the inlet to the outlet. We use one side at a time and the sludge slides down this one side and piles up close to the slot.

Mr. Currie: The sludge should settle equally across the tank and not pile up. If the sludge piles up it is a very unusual sludge. Do you use a chain to clean the slot?

Mr. Drake: We use a long handled spade.

Mr. Currie: I would recommend the chain; you can then be surer of getting it all the way down.

Mr. Scott: It may be that the baffle, which was added after the plant was designed, may have something to do with its inefficient operation.

Mr. Higgins: Is there much scum?

Mr. Drake: Sometimes about 18 inches, and sometimes scarcely any.

Mr. Higgins: Is there no foaming?

Mr. Drake: Practically no foaming.

Mr. Higgins: Do you remove the scum on the gas vents?

Mr. Drake: Yes.

Mr. Currie: I would suggest that you let the scum on the gas vents get hard, and cut a hole in it for the gas to come through. This will also help in eliminating the odor.

Odors from Tanks

Mr. Drake: The odor is about our worst trouble. The baffle was to cut down the odor. If we could eliminate the odor we could get along with the other troubles. People complain about the odor.

Mr. Wieters: Odor is just an indication that your plant is not working perfectly. How does the sewage get to the plant, by siphon or by gravity flow?

Mr. Drake: It comes about one-half mile through a large pipe to the plant.

Mr. Wieters: There might be some putrefaction before it reaches the plant.

Mr. Murphy: You doubtless have all experienced the difficulty of bad odor conditions in hot weather. It will be interesting to exchange experience on that matter. How have you reduced the odors about the plant to the greatest extent?

Operator: The only thing we have done is to clean up the plant by drawing the sludge and liming the tanks.

Mr. Morris: I think you get more odor sometimes than others. The

matter of settling has something to do with it, then we thoroughly skim the flowing-through chamber. It is also a good thing to get a scum over the gas vent, leaving a hole for the gas to escape.

Mr. Ward: I have found in our plant that if we keep the scum on the gas vents thoroughly stirred and broken up we get less odor. I break up the scum once during the day and once during the night, and do the same with the flowing-through chamber. I think that is the way to keep odors down.

Mr. Murphy: Mr. Ward apparently gets results in preventing odors by keeping the scum on the gas vents thoroughly broken up. What has been your experience at Mason City, Mr. Bufkin?

Mr. Bufkin: I find that we get more odor when the flow of sewage through the plant is less than the normal capacity, and when the plant is running at normal capacity the odor will disappear.

Mr. Currie: I think Dr. Imhoff made the statement that too much water is used in our settling tanks. If water is necessary to spray on the gas vents, use the water in the tank itself. The addition of fresh water inhibits digestion. There are some plants where spraying is necessary to keep down foaming. However, I think you will find that the scum on the gas vents will keep down odors. Just cut a hole in the scum to let the gas escape. I saw one plant where there were tomato plants four feet high growing on the sludge and gas vents, and the plant was functioning fine. You just have to watch the scum close enough to see that it does not build down to the sludge.

Operator: I think the odor of the scum is the worst. You get the odor of the gas anyway, whether you leave the scum or not.

Mr. Mark: This summer I visited the plant at Spirit Lake. They have found that the addition of hydrated lime considerably reduces the odor.

Mr. Scott: The use of chlorine is particularly good where you have a long sewer leading to the plant and there is a possibility of septic action before the sewage reaches the plant. This, of course, disturbs the action of the whole plant.

Mr. Stanley: You might be interested in the plant in North Chicago. The town has a population of around 8000. There is a flow of about 1,000,000 gallons per day into the Imhoff tank. There is a chemical plant, connected with the city sewer, where the compound "606" is manufactured. The result is that there is no activity whatever in the tanks as far as digestion is concerned. We get this same problem where there is a creamery in a small town. The lactic acid disturbs the alkaline condition necessary for proper digestion.

Mr. Ward: How would you explain why one tank foams and one does not?

Mr. Currie: You are evidently getting better digestion in one tank than

the other. Try putting the main part of the sewage in the tank that is not foaming. You are lucky that the other one does not start.

Odors from Filters

Chairman: Are there any further questions on this matter? Are there any questions on odor control?

Question: How much chlorine do you need to control the filter odors?

Mr. Boyce: It is not necessary to add enough chlorine so there will be a residual left in the effluent. All that you want to do is to kill the bacteria that produce a putrefactive condition in your plant.

Mr. Wieters: Does anyone have any further questions? We will take up the matter of sewage disinfectants.

Mr. Boyce: Frequently those who are interested in cleaning up streams have in mind the object of keeping the streams in condition for fishing and bathing and that brings up some problems in chlorination. It is effective on sewage that has been oxidized, but the sewage must be fresh in order to absorb it. In one instance we tried chlorinating the sewage twice, once before it entered the plant and once as it left the plant. One thing that interests me is that sewage disposal plants often take wastes like those from tuberculosis institutions and use chlorine on the effluent. Tests have shown that chlorine has no effect on the tuberculosis bacilli. Also the bacilli of anthrax and tetanus are not touched by the ordinary concentration of chlorine.

Mr. Wieters: Are there any questions about filter flies? Mr. Galligan, you are familiar with the experiment with filter flies at Mason City.

Mr. Galligan: They tried spraying to kill the flies. That gets rid of them temporarily.

Mr. Bufkin: We had the experience of having a great many flies and tried all sorts of ways to get rid of them. About the time we got rid of them the filters started clogging. It was the opinion at Mason City that the flies keep down the heavy growth on filters, for when the flies were removed the growth clogged the filters.

Mr. Wieters: What was the nature of the spray test?

Mr. Bufkin: Chlorine, but we had tried so many things that we were never sure just what had killed the flies.

Mr. Wieters: Are there questions on the matter of filter growths?

Mr. Warrick: At Elgin they were troubled with large numbers of flies and also with clogging of the filters. The operator came up to Madison and got some *Achorutes Viaticus* and placed them on the filter, but from all appearances they died. Then they chlorinated the filter, and shortly afterward they noticed the *Achorutes Viaticus* were developing in the filter bed. I can't say whether or not the chlorine brought about the condition.

Question: I would like to hear about Madison.

Mr. Warrick: The *Achorutes* have kept down the fly nuisance at Madison and seem to be thriving very well. The sewage there is a combination of domestic sewage and packing-house waste. The water spring-tail (*Achorutes Viaticus*) has not developed so rapidly in the new plant and I do not know just the reason for the failure. That is one line of research for the biologists to find some way of transporting them. They seem to die when transported.

Mr. Currie: There are one or two plants in California where the spiders keep the flies down. It was also found difficult to transport these spiders, for like all native Californians they seemed to prefer their own state.

Mr. Murphy: Are there any other experiences along these lines?

Operator: Does anyone have any data on the problem of whether or not filter flies have any influence on the operation of the filters? Some people claim they do.

Mr. Murphy: The research in this field is still in the early stages.

The Control of Algae and Filter Flies in Trickling Filters. C. C. HOMMON. *Amer. City*, 1930, **43**, No. 2, 11. At Canton, Ohio, algal growths on the top of sprinkling filters have been controlled by allowing the filters to remain dry for 24 hours once a week. A satisfactory method has also been developed for controlling filter flies by flooding the filter for 24 hours once every 11 days during the warmer months. This treatment has caused a decided sloughing-off of the organic matter from the slag medium and has kept the filters clean. According to the author's experience, excessive amounts of organic matter within the filter tend to retard the development of the filter fly. The success of the method of cleaning filters by drying and flooding depends largely on the size of the aggregate. If the aggregate is small, the filter may clog rapidly and drying and flooding are not effective. The method has proved effective, however, where the aggregate is well graded and does not contain much material smaller than $1^1/_2$ in. in diameter.—Abs. No. **446**, *British Summary of Current Literature, Water Pollution Research*, Vol. IV, 4 (April 1931).

How Jackson County Solved Its Troublesome Sewage Disposal Problem

BY R. E. MCDONNELL[1]

The Jackson County Farm is in effect a small municipality of 1000 aged people supported and controlled by Jackson County, Missouri. Its location is some ten miles from the city limits of Kansas City, Missouri, and about one-half that far from the nearest existing sewer system.

The farm comprises 380 acres of very rugged land, the difference in elevation between the lowest and highest point being in the neighborhood of 130 feet. On the highest points of two hills 3500 feet apart are located, respectively, the quarters for negro and white inmates of the farm. Between the two hills is a comparatively deep natural draw or ravine. Drainage slopes away from both quarters in all directions but wastes from the farm must travel through intermittent stream beds from one and one-half to three miles before reaching the Little Blue River.

The topography of the farm makes the building of a sewer line for any great distance an expensive task. For years the problem of building an outfall sewer to carry the sewage to some common point of disposal away from the buildings had been entirely avoided. The sewage was merely discharged untreated into ravines a short distance from the buildings and the resulting conditions were disagreeable throughout the entire vicinity. The original plan of treatment was to pass the sewage through small septic tanks located a short distance back of the respective buildings before discharging into the ravine. These tanks were insufficient in size and in later years were completely bypassed, since treatment was entirely ineffective.

A progressive administration in Jackson County sought to eliminate the insanitary conditions existing on the farm.

An outfall sewer was built under great difficulties at a cost of $25,000. The sewer is 6530 feet long, with 622 feet of its length supported on a trestle crossing a ravine at a height of twenty feet. The average trench excavation was about twelve feet and more than 700 cubic yards of rock were removed from these trenches.

The treatment plant built is an activated-sludge plant of the mechanical-aeration type. It produces an effluent which is satisfactory to dispose of in a dry drainage ditch. The plant structures consist of a screen chamber, a preliminary settling basin, two aeration tanks, a final clarifier, a sludge-pump station, a sludge-digestion tank and a sludge drying bed.

The operation of the plant may best be understood by following the successive steps of treatment.

[1] *Burns & McDonnell Engineering Company, Kansas City and Los Angeles.*

The incoming raw sewage flows from the outfall sewer through the screen chamber. Here a coarse screen, bars spaced at one and one-half inch centers, removes the floating materials, rocks, sticks and rags, which are likely to hamper operation in the plant or to be injurious to the mechanism.

From the screen chamber the sewage flows into the primary settling tank. The tank is large enough to provide for a two-hour retention period for the design flow, in which time as much as 60 per cent of the settleable solids are taken from the sewage. These solids are drawn off from the bottom

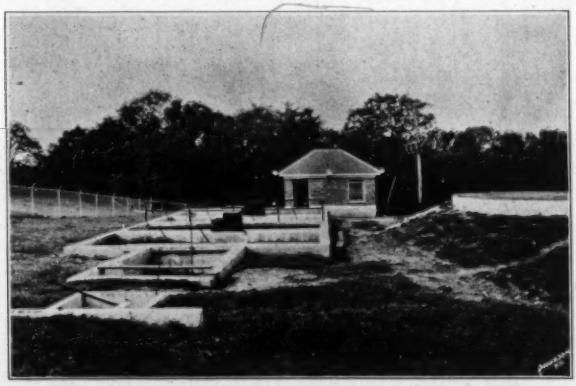


FIG. 1.—Jackson County Treatment Plant. Screen Chamber, Preliminary Settling Tank and Aeration Tanks in Foreground, Digestion Tank to the Right.

of the tank and are disposed of by decomposition in the sludge-digestion chamber.

After leaving the primary settling tank the sewage is ready for treatment by the activated-sludge process. One part of activated sludge is pumped from the final clarifier and mixed with five parts of sewage at the entrance to the aeration unit, after which the mixture is violently agitated in the presence of air. The aeration mechanism consists of a light tube 3 ft. in diameter and 11 ft., 9 in. long (6 in. less than the water depth of the tank) suspended vertically in the center of the tanks. At the top of the tube a revolving cone 6 ft. in diameter, provided with vanes, pumps the sewage from the bottom of the tank up through the tube and throws it out in a thin sheet through the air over the surface of the tank. There

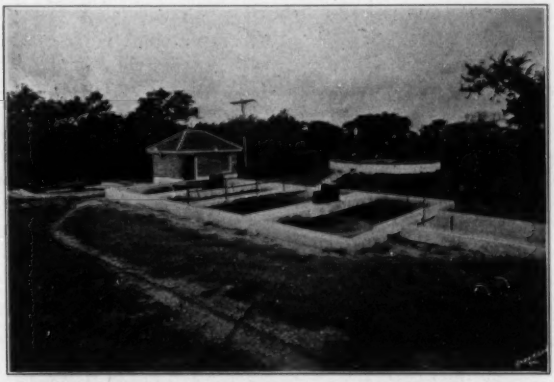


FIG. 2.—Jackson County Treatment Plant, Showing Preliminary Settling Tank, Aeration Tanks, Final Dorr Settling Tank, Sludge Pumping Station and Sludge Digestion Tank.

are two such tanks, each with a capacity for an aeration period of 10 hours and so interconnected that they may be used in series or parallel operation.

Settlement is provided for in the final clarifier, which is provided with a traction-type clarifier mechanism.

The detention period in the final clarifier is approximately two hours. As sludge settles to the bottom of the tank, a slow revolving arm equipped with squeegees scrapes the sludge into a center opening, from which

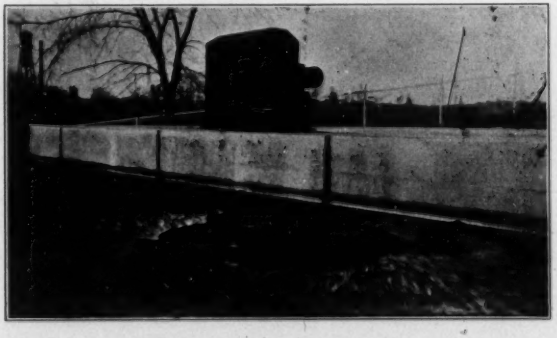


FIG. 3.—Simplex Aerator in Operation.

it is removed by a sludge pump. Part of the sludge drawn is deposited in the sludge digester and the remainder is returned to the aeration tank. The effluent from the tank is discharged into a dry stream bed, and flows through this ordinarily dry ravine for a distance of three miles before reaching the Little Blue River, without the least offense to abutting property owners. The construction and satisfactory operation of the plant has eliminated all complaints from adjoining property owners.

The sludge digestion tank in which the activated and raw sludge is stored is a circular storage tank, in which digestion of the organic solids occurs, the principal final products of digestion being stable humus-like matter and methane gas, neither of which has any pronounced odor.

Sludge will digest or become stable in about six months time in this digester.

Removal of the digested sludge is accomplished by draining from the bottom of the tank to the sludge drying bed. This bed has a system of underdrains beneath a layer of sand.

The digested sludge has a dark brown earthy appearance and is non-offensive to sight or smell. It has value as a fertilizer, which can be increased by adding phosphate. The dried sludge is easily scraped from the sand beds and may be deposited as fill garden soil. The dried sludge will be used as a fertilizer on the County Farm gardens, lawns and flower beds.

The cost of the treatment plant was $30,000. It is designed to care for an ultimate population of 2000 inhabitants. The plant requires only intermittent attention for oiling and caring for the machinery. It has eliminated unhealthful and unpleasant conditions on and in the vicinity of the Jackson County Farm. The entire improvements were carried through under the direction of the Jackson County Court of which Harry F. Truman is the Presiding Judge.

The consulting and designing engineers were Burns & McDonnell Engineering Company, Kansas City, Missouri, and the general contractor was the Merkle Contracting Company, Kansas City, Missouri. The aeration equipment was furnished by the Simplex Company, of Chicago; and the pumps and clarifier mechanism were furnished by the Dorr Company, of Chicago.

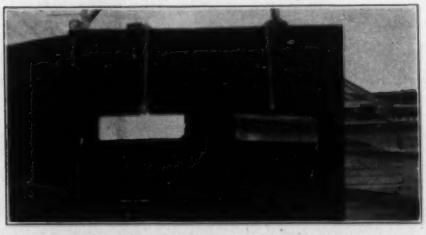
Tracing Mineral Oil in Sanitary Sewers at San Antonio, Texas

BY W. S. STANLEY[1]

One of the most annoying problems confronting the sewage plant operator is the waste mineral oil promiscuously dumped into sanitary sewers. Most of the larger cities have ordinances prohibiting such practice, but unfortunately such ordinances seldom have teeth in them and are difficult to enforce.

The City of San Antonio, Texas, with a population of 250,000, disposed of its sewage by broad irrigation prior to construction of an activated sludge plant. Little attention was paid to oil in the sewage. In July, 1930, the activated sludge plant was close to completion, when it was found that the amount of oil in the sewage was so great that it would be impossible to build up activated sludge without elimination of the oil.

Tracing the sources of mineral oil presented the hardest problem. It was decided at first to approach places which would most probably be the largest contributors of this nuisance. Visits were paid to garages, filling stations, machine shops and railroad yards, explaining in each instance the harm caused by the practice of dumping oil into sewers. No coercion was used, but appeal to the civic pride of the owners or managers was made. At the same time an educational campaign was carried through the public press, pointing out the necessity of safeguarding of the new sewage plant, which was built at a cost of $900,000.



Floats Used in Tracing Oil in Sewers. Left: Float before Use. Right: Float Showing Oil Ring.

The results of this campaign were quite gratifying, but most of the places approached disclaimed violation of anti-oil dumping ordinances, so that it was impossible to isolate the real offenders, and the oil, although diminishing in quantity, was still polluting the plant. To obtain tangible evidence and confront the guilty parties with actual proof of violations, the following procedure was finally adopted:

A number of wooden floats were suspended in manhole openings at the

[1] *Chief Chemist, San Antonio Sewage Treatment Plant.*

intersections of main and lateral sewers in such manner as to float in sewage at low tide. The floats were 6 × 6 inches square, made of 2-inch lumber, painted with flat white paint. They were equipped with screw eyes for attaching a strong fishing line, which in turn was tied to manhole steps.

The coat of flat white paint, coming into contact with oil floating at the surface of the sewage, retained a distinct black oil line. By examining the floats periodically, every two or three days, it was possible to eliminate sewers which showed no oil pollution, and to follow up lines contributing to the nuisance. In this manner, by process of elimination, we were able to isolate sections which showed the greatest amount of oil, and finally to trace individual offenders. When confronted with actual proof of the violation, the responsible parties without exception agreed to remedy the trouble, some going to considerable expense in building elaborate oil traps.

As a consequence, after a vigorous campaign which lasted approximately three weeks, the oil was eliminated. Upon rare occasions we still receive a slug of oil, but since the floats remain in service at strategic points, we have no trouble in tracing its source.

Investigations into Benzol Separators. O. KAMMANN AND H. MÜLLER. *Tech. Gemeindebl.*, 1930, **33,** 81. The authors give a list of recent explosions in sewers in German cities, which were due to the presence of benzol. An account is given of an investigation of separators at a large number of garages and repair works of different sizes. The results showed that, though a number of works possessed separators in excellent working order, about 30 per cent of those in control knew nothing about the operation of the separator, which was generally in a neglected and useless condition. Some form of automatic closing of the outlet to the sewer is advisable. Richter's description of the development of separators (*Gesund.-Ing.*, Supplement, 1927, Part 5) is referred to, and a form of separator recommended by him, in which a float closes the outflow as soon as the separator has collected its maximum amount of light oil, is illustrated. An illustration is also given of a newer model of the Dywidag Company, which can also be supplied with an automatic closer. Fuel technologists should interest themselves in discovering some means of using this waste for boiler heating. The separation of the oil into its constituents would not be economically possible even if several towns combined, as carriage costs would be too great. The present requirements are, therefore, education of the responsible persons, constant supervision by the directing authority, and regular arrangements for the removal of the oil.—Abs. No. **970,** *British Summary of Current Literature, Water Pollution Research*, Vol. III, 8 (August, 1930).

Cost of Sewage Treatment at Elgin, Illinois[1]

BY E. E. SMITH[2]

The Sanitary District of Elgin is a municipal corporation organized for the express purpose of collecting and treating the sewage of the District to prevent objectionable pollution of the Fox River. This District has been organized since 1922 and has had a modern type of sewage treatment works in operation since June, 1927.

The actual costs of sewage treatment at Elgin are met by taxes raised for the operation of the Sanitary District. In order to understand such costs clearly, it is necessary to classify the total costs into separate units such as construction costs, operating costs and general overhead costs.

Taxes Collected.—The taxes that have been collected for the operation of the Sanitary District of Elgin since its organization are as follows:

Year	Taxes for Interest and Retirement of Bonds	Taxes for General Operation
1923	.....	$43,998.86
1924	$17,500.00	45,018.34
1925	54,500.00	44,267.50
1926	55,450.00	45,490.13
1927	56,300.00	48,225.47
1928	57,050.00	48,909.37
1929	55,750.00	50,582.77
1930	56,400.00	51,694.61

These figures show that the total amount of taxes collected for all purposes for the last six years has averaged about $104,100 per year, or about $3.00 per capita per year based on a present population of 35,000. These collected taxes have been used to meet current expenditures.

The expenditures of the Sanitary District to date have included:

(*a*) Fixed charges on bonded debt
(*b*) Direct operating expenses
(*c*) Organization overhead
(*d*) Construction costs.

These expenditures have used up the total amount of taxes which legally can be collected by the Sanitary District.

The following costs are taken from the records of the Sanitary District of Elgin since its formation in 1922. The construction costs include the total expenditures to May 1, 1930. All per capita cost figures are based on a district population of 35,000 persons. The total population of the District is 36,800, which includes a part of the Elgin State Hospital, with a total of 1800 patients. This hospital is not connected to the sewer system nor does it pay taxes.

[1] *Presented before Meeting of the Illinois Society of Engineers, Rockford, Ill., January, 1931.*

[2] *District Superintendent.*

The total construction cost was $476,619.69 for the sewage collection system, including intercepting sewers and three pumping stations with a total of eleven pumps of different sizes. This amount represents a per capita cost of $13.61.

The treatment plant consists of a grit chamber, four Imhoff tanks, trickling filters 8 feet deep, with an area of 1.54 acres, two secondary tanks, sludge pump house and sludge pumps, twelve sludge beds complete with industrial track and locomotive, and a two-story office building. This plant was constructed at a total cost of $378,275.46, or a per capita cost of $10.81.

Land necessary for the treatment plant and pumping station sites was acquired for $12,789.09, or a per capita cost of $0.37.

The total cost of engineering services, which include consulting, district, assistants, inspector and all equipment, was $83,205.17, or a per capita cost of $2.38.

The summarized total cost for land, construction and engineering, to May 1, 1930, was $950,886.41, or a per capita cost of $27.17. These per capita costs are not out of line with the costs of similar works elsewhere, as indicated by the following data:

Place	Approximate per Capita Costs of Sewage Disposal Project
Springfield	$33.85
Decatur	32.20
Peoria	26.80
Rockford	28.80
Aurora	24.00
Urbana-Champaign	18.20

Cost in Relation to Design per Million Gallons.—The intercepting sewers are constructed for a future population of 75,000 persons, which at a rate of 246 gallons per capita per day gives a capacity of 18.5 million gallons per day. On this basis the interceptors cost about $25,800 per million gallons capacity.

The treatment plant was designed for a population of 37,500 persons at 88 gallons per capita, or 3.3 million gallons per day. At this capacity the treatment plant cost about $114,600 per million gallons.

Cost of Operation.—The cost of operation is of most interest to the plant superintendent or operator. Operation costs at Elgin include all salaries of office and operating personnel, two automobiles replaced about every two years, with their maintenance and operating costs, repairs and renewals to structures and mechanical equipment, laboratory supplies and equipment, and office supplies.

The total cost of operation, not including power, for the past two years has been $34,128.14, or about $17,000.00 per year, or a per capita cost per year of $0.49.

Cost per Million Gallons of Sewage Treated.—The total cost of

sewage treatment at the Sanitary District of Elgin treatment works is $19.48 per million gallons. This is divided as follows:

Operating expense	$11.80
Electric power	5.42
Organization overhead	2.26
Total	$19.48

With an average daily flow of 3,963,000 gallons of sewage for the past two years, the average cost to the Sanitary District for the treatment of sewage has been $77.20 per day. This includes only operating expenses and does not include fixed charges.

There are three pumping stations for elevating the sewage to the treatment plant. The motors in these stations range from 20 to 75 horsepower. It is also necessary to repump seventy-five per cent of the sewage at the main pumping station which increases the electric power costs; therefore, it is desirable to keep the electric power costs separate from other operating costs. Due to these conditions and repumpage the total cost for electric power has been $15,667.70 for the past two years, or an average of about $7800 per year, or a per capita cost of $0.22 per year.

In addition, the cost of operation must provide for organization overhead, because there are certain items that cannot be charged directly to operation, but should be taken into consideration for the total operating cost. Principally among these items are legal expenses, traveling expenses, office furniture and equipment, trustees' salaries and miscellaneous expenses. The total cost of our organization overhead is approximately $3300 per year, or a per capita cost of $0.09 per year.

Total Cost to Taxpayer on per Capita Basis.—Total cost to taxpayer, as indicated by taxes collected, includes the foregoing operating costs and, in addition, fixed charges on the bonded debt and cost of replacements and extensions.

The fixed charges for the bonded debt of the Sanitary District of Elgin require a payment of approximately $55,970 average per year over a 20-year period, beginning 1925. At this rate the fixed charges per capita are $1.60 per year and $38.60 per million gallons of sewage treated, based on present flows.

The sum total of the fixed charges and annual operating costs amounts to $2.40 per capita per year, as follows:

Fixed charges (bonds and interest)	$1.60
Operating expenses	0.49
Electric power	0.22
Organization overhead	0.09
Total	$2.40

Total operation and fixed charges may be combined as follows:

	Operation	Fixed Charges (Bonds & Interest)	Total
Per m. g.	$19.48	$38.60	$58.08
Per capita	0.80	1.60	2.40

The difference between the cost of $2.40 a year and the $3 per capita taxes raised per year represents amount of new construction work which has been required to organize completely the Sanitary District of Elgin. It is anticipated that an amount corresponding approximately to this $0.60 per capita per year will be required in the future to meet the cost of necessary replacements and extensions, which will be required to keep the capacities up to the demands of the community and to dispose of the sewage properly.

What citizen, if the data were presented in this way, would hesitate to invest $3 per year if it would insure the cleaning up of the streams, the betterment of health conditions and the return of fish life to the streams, with the added satisfaction of knowing that he was taking care of his filth and wastes instead of dumping them upon the communities down-stream?

$100,000 Revolving Fund Built Complete Sewerage and Sewage Disposal System. F. S. FRIEL. *Amer. City*, 1930, **43**, No. 5, 96. The method used to finance the construction of a sewerage system and sewage treatment works for the borough of Bridgeport, Pa., on the Schuylkill River is described. The sewerage is on the combined sewage and storm water system, the main outfall sewer intercepting the full dry weather flow and a quantity of overflow storm water equal to 10 per cent of the dry weather flow. This represents the first flush of rainfall and carries deposits from the sides of sewers and washings from the street surface. The entire sewage flows by gravity through screens and a two-channel grit chamber (which is emptied and cleaned after every storm) to the pumping plant by which it is raised to the treatment works. Sedimentation and chlorination are the only treatments applied.—Abs. No. **425**, *British Summary of Current Literature, Water Pollution Research*, Vol. IV, 4 (April, 1931).

Industrial Wastes

The Effects of Industrial Wastes on the Operation of Municipal Sewage Treatment Works[1]

By L. F. Warrick[2]

Many municipalities are confronted with industrial waste problems in the maintenance and operation of sewerage and sewage treatment works. These problems have been created or intensified during recent years through the phenomenal development of industry in this country, with our cities and villages being converted into large manufacturing centers. Municipal sewerage systems have been utilized for the disposal of liquid trade wastes, often of such character or in such great amounts as to result frequently in difficulties or objectionable conditions at sewage treatment plants and in streams and lakes ultimately receiving the wastes. Accordingly, it is proposed herein to outline some of these difficulties, describe a few typical situations and, finally, to emphasize the desirability of coöperative action by municipal and industrial plant officials in securing satisfactory solutions for various sewage and trade waste treatment problems.

Industrial wastes, the physical and chemical characteristics of which vary considerably from those of domestic sewage, when discharged into municipal sewerage systems, have been responsible for such objectionable effects or conditions, as follows:

1. Accelerated deterioration of sewers and sewage treatment plant structures.
2. Interference with normal processes of domestic sewage treatment, particularly with respect to
   (*a*) Removal and digestion of sewage solids
   (*b*) Sludge disposal, and
   (*c*) Biological oxidation processes.
3. Failure of sewage works to remove certain kinds of pollutional constituents from some trade wastes.
4. Operating difficulties for the sewage treatment plant operating personnel, and
5. Increased sewage treatment costs.

Overloading of sewage treatment plants by excessive volumes of trade

[1] *Presented at Fourth Annual Meeting of the Iowa Wastes Disposal Association, Ames, Iowa, Nov. 15, 1930.*

[2] *State Sanitary Engineer, Wisconsin State Board of Health.*

wastes has been the cause of a considerable number of nuisances and conditions of gross pollution.

An outstanding case of sewage treatment plant overloading by industrial wastes was found in a small city in Wisconsin. This municipality has a population tributary to the sewerage system of approximately 1200 people, and the sewage is given partial treatment in an Imhoff tank prior to discharge into a creek affording limited dilution. A large creamery was connected to the system, discharging into the treatment plant a considerable volume of milk wastes, including some buttermilk and whey. Later a three-line pea canning plant started discharging 50,000 gallons per day of washings, 30,000 gallons per day of cooling water and the silage juice from about 800 acres of stacked vines, into the city sewers. Under normal conditions the Imhoff tank would furnish approximately $3^1/_2$ hours detention period for the domestic sewage, but with the addition of the creamery wastes the detention period was reduced to about $2^3/_4$ hours. During the time when this tank was receiving both the wastes from the creamery and the canning plant, the detention period was only 28 minutes. It is almost needless to state that treatment efficiency tests gave negative results.

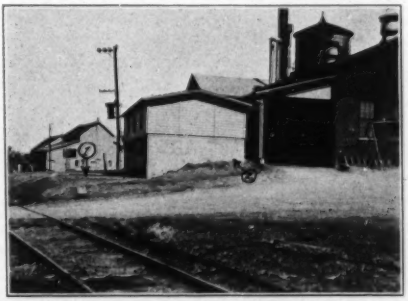


FIG. 1.—Preliminary Treatment of Milk Plant Wastes Is Frequently Necessary to Prevent Operation Difficulties at Sewage Disposal Works in Small Municipalities. A Biological Filter Installation at a Wisconsin Creamery Is Shown Above. (1) Collecting Sump for Wastes and (2) Covered Rock Filter.

Considerable difficulty has been experienced with foaming in this Imhoff tank, and accordingly it has been necessary to build up the walls around the gas vents about 4 feet. At times these walls are found to be insufficient to prevent the overflow of foaming sludge. It was found impossible to remove much sludge from the digestion compartment of the tank in the ordinary manner, due to the fact that the bulk of the solids were to be found at the top of the tank in the gas vents. Since the foaming was experienced after the creamery was connected to the sewerage system and before the canning plant wastes were added, this type of operating difficulty can be attributed to excessive amounts of untreated creamery wastes.

That milk wastes are responsible, for ineffective operation of municipal disposal plants was further demonstrated in a village which recently installed a sewerage system and treatment works. As in the foregoing case, treatment was in the form of an Imhoff tank. Only about 135 connections were made to the system, resulting in a small volume of domestic sewage to be handled by the plant. Wastes from a cheese factory with a milk intake of about 60,000 pounds daily, after preliminary treatment in a septic tank, were allowed to discharge into the village sewers. As a result the per cent reduction of settleable solids was almost negligible, and the stream receiving the plant effluent gave ample indication of ineffective treatment.

Recently preliminary treatment for the cheese factory wastes, with the exception of whey, has been provided and has already resulted in marked improvement in sewage disposal plant operation. This preliminary treatment is in the form of biological filtration for the vat, floor and utensil washings, the whey being returned to the cheese factory patrons for use on surrounding farms for stock feeding purposes. Consideration is now being given to the installation of drying equipment and the recovery of the solids in the whey in the manufacture of valuable food products. The pretreatment of the washings is accomplished by a crushed granite filter, eight feet in depth, intermittently dosed by means of tipping troughs. The construction of this filter was based upon results obtained in experimental work conducted at DeForest, Wisconsin, and information concerning similar work in Iowa, Ohio and Michigan.

Some industrial wastes have strongly acid characteristics and are found to cause disintegration of the sewerage systems and treatment works, unless given preliminary treatment to neutralize the acids. A typical waste of this nature is the pickling liquor from steel mills and other metal working industries. Some chemical manufacturing establishments also produce such wastes.

Difficulties in sewage treatment due to the wastes from woolen mills have been experienced. This type of waste contains a large amount of short wool fibers, which adhere to sewage solids, and seem to exert a binding effect. With a sufficient quantity of this type of waste it is very probable that a tough scum will be formed and a large portion of the sludge found at the top of Imhoff and separate sludge-digestion tanks.

Packing-plant effluents contain a considerable amount of grease which will not settle and must be removed by skimming processes, either at the packing plant or at sewage treatment works. Unless special facilities are provided for handling grease, the skimming process occasions considerable labor for a plant operator.

Oil wastes from industries, garages, filling stations, etc., are often responsible for objectionable conditions when discharged into sewerage systems and treatment plants. A relatively small amount of oil will

very materially interfere with the efficiency of operation of an activated-sludge plant. This type of waste should be excluded from a municipal sewerage system.

Wastes produced in the manufacture of beet sugar, gas, coke, leather textiles, paper and a number of other products offer special problems when disposed of with municipal sewage. Satisfactory and economical solutions for many of these problems are yet to be obtained.

Reduction of the volume and strength of industrial wastes to a minimum before discharge into municipal sewerage systems is often essential in overcoming difficulties outlined. Re-use or utilization of the wastes in the manufacture of valuable by-products have in some instances overcome or materially reduced these difficulties. Re-use of white water in paper mills and recovery of phenol at by-product coke plants are examples of waste utilization procedures. Sometimes these procedures are found to be decidedly to the economic advantage of industries involved.

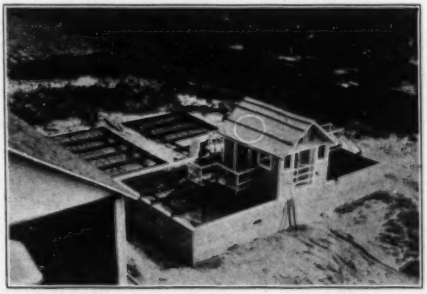


FIG. 2.—Screening and Chemical Treatment of Pea Canning Wastes in Fill-and-Draw Plants, Such as Shown Above, Have Overcome Operating Difficulties Caused by These Wastes at Sewage Disposal Works.

In cases where trade wastes cannot advantageously be utilized, the problem generally resolves itself into securing some effective method of preliminary treatment. For instance, at the present time in Wisconsin the problems offered by pea canning wastes are being taken care of by the installation at the canneries of screening facilities and fill-and-draw types of chemical treatment units. The treatment afforded by these installations has satisfactorily overcome difficulties previously experienced at sewage disposal plants receiving the wastes.

The results of experimental work in the treatment of cannery wastes in Wisconsin demonstrate that:

1. For the removal of gross solids, mechanical screen units covered with 40-mesh wire are found to be most satisfactory and constitute a very essential part of any treatment system. Every canning factory should be equipped with effective waste-screening facilities.

2. For further treatment of the screened waste to reduce objectionable

organic matter 50 to 75 per cent as measured by the oxygen demand, it is necessary to apply $3^1/_4$ pounds of ferrous sulphate and $7^1/_4$ pounds of lime per thousand gallons of pea canning wastes; $2^1/_4$ pounds of ferrous sulphate and 6 pounds of lime per thousand gallons of wax bean wastes; and $3^1/_4$ pounds of ferrous sulphate and 6 pounds of lime per thousand gallons of corn wastes. Thorough mixing of the chemicals with the waste and a settling period of at least one hour are required to insure proper treatment. Mixing previously precipitated sludge with fresh wastes retards the settling rate. Daily removal of the sludge is essential.

3. A trickling filter constructed of crushed limestone 8 feet in depth will reduce the oxygen demand of pea canning waste remaining after chemical treatment 35 to 84 per cent if the volume of wastes applied does not exceed three million gallons per acre of filter area per day. About two weeks of operation were required before the filter became effective.

4. Operation costs of chemical treatment plants varied from 0.34 to 0.78 of a cent per case of No. 2 cans of peas. Total waste treatment charges, including depreciation estimated at 10 per cent, should not exceed one cent per case of No. 2 cans of peas. The cost of a treatment plant properly designed, constructed and equipped for the treatment of wastes from a three-line pea cannery was $3500.

5. Sludge produced by proper chemical treatment dries rapidly on sand beds and has no appreciable odor. It has a fertilizer value of about $3.50 per ton, sufficient to warrant its removal and use on nearby farms.

6. Disposal of the factory wastes by broad irrigation was not found satisfactory for general application. It may be possible, in exceptional cases, to dispose of the wastes by this method on exceedingly porous soil, and at isolated sites where odor control is not essential. Control of odors by chlorination, with this method of disposal, is limited in effectiveness.

In the case of pea canning wastes the volume of the wastes is large and the period of operation of the factory is usually in the neighborhood of six weeks. If small municipalities were to attempt to provide satisfactory treatment for pea canning wastes, it would be necessary for them to double if not triple the capacity of their plants in order to take care of this waste, which is discharged for only a period of six weeks. This would mean a considerable investment for a municipality in order to take care of the wastes from one factory. On the other hand, the type of treatment required to treat this type of waste would not be entirely satisfactory for the treatment of domestic sewage.

Difficulties will be continually encountered in the disposal of trade wastes through public sewerage and sewage treatment plants unless careful study is given each problem by both industry and the municipality. These problems should be considered both from the points of view of,

first, waste recovery and, secondly, modification of waste characteristics to allow satisfactory treatment and disposal with the domestic sewage.

Cities and villages should assume responsibility for the maintenance of proper sanitary conditions within the areas of their jurisdiction. They should, therefore, furnish general supervision over the operation and maintenance of all local installations for the disposal or pre-treatment of industrial wastes in order that effective results may at all times be secured.

In conclusion, it is desired to emphasize that the industry and municipality are mutually concerned in the satisfactory disposal of wastes. Frequently industries are induced to locate in municipalities by the offer of sewerage and other facilities. The success of the industry is frequently vital to the development of the municipality. The problem, therefore, becomes one requiring coöperation on the part of both the municipality and the industry.

Discussion on Treatment of Industrial Wastes

Mr. Murphy: Practically every municipality must face this problem, and it is good that we can have a statement of conditions brought before us in this way.

Mr. Wieters: I would like to ask Mr. Warrick what he thinks of this chemical treatment for corn wastes. We have only one exclusive pea cannery and many corn factories in this state. I understand that the work he mentions has been done largely on peas, but that there is some on corn.

Mr. Warrick: Corn cannery wastes vary somewhat from pea cannery wastes. The oxygen demand reduction is not so great with the corn wastes, but after secondary biological treatment they can be assimilated by a stream, affording limited dilution. The treatment cost is not excessive, from one cent to one and one-half cents per case of corn. Many of our canneries in Wisconsin pack peas alone, and what corn is canned is usually canned in the same factories with other vegetables so there has been little work done exclusively on corn.

Mr. Wieters: I would like to ask Mr. Warrick one question. I understood you to say that the State Board of Health and the canners of Wisconsin had agreed that, regardless of location, all pea canneries should provide screens. Do you think the same should apply to corn?

Mr. Warrick: Yes, I think that regardless of the treatment to be used the screen is necessary.

Mr. Drake: I would like to ask Mr. Warrick about packing-house wastes in Wisconsin. If they are bothered with the same troubles that we are, and, if so, what they do about them.

Mr. Warrick: We have several packing-house waste problems. In Madison there is a packing-house where they give the waste preliminary

treatment in the form of a clarifying unit. The grease comes to the surface and the solids settle out and are recovered by the packing plant. The wastes are then sent to the disposal plant and are there put through a preliminary treatment for the removal of greasy substances that have been carried over. It seems that some of these solids settle out very slowly so the wastes are then passed into one separate unit of the disposal plant sedimentation tanks before being passed into the contact unit and out on the trickling filter. After this it has been found that the waste can be discharged into the local lake without offense. The combined waste from packing plant and domestic sewage has a 5-day B. O. D. from 1000 to 1500 parts per million.

Mr. Drake: Is it advisable to attempt to settle out solids by chemicals?

Mr. Warrick: That was given some consideration in the preliminary tests at the University of Wisconsin and was passed up as being of little benefit. The use of chemicals might, we thought, create a problem of sludge disposal.

Mr. Drake: Could you say what chemical treatments were tried at the university?

Mr. Warrick: Acid treatments were used and so were various sulphates and other precipitants, but in just what proportions, I don't recall.

Mr. Wieters: We seem to have drifted from cannery wastes to packing-house wastes. Are there any further questions on cannery wastes?

Question: I would like to ask what is the best depth for a filter in order to get a good effluent from canning factory sewage?

Mr. Warrick: The depth should be about eight feet. It should be emphasized, however, that every cannery offers a special problem. Local waste treatment requirements must be taken into consideration.

Mr. Galligan: We have a filter of a depth of six feet at Slater, and at Glidden one that is seven feet in depth. Both of these care for creamery wastes. We have not enough data to state definitely as to what degree of treatment we can expect. At Glidden we have found an 85 per cent B. O. D. reduction through the seven-foot filter. It has been operating since June 28, 1930, with no difficulty except clogging. It is my opinion that in treating creamery wastes we should pay more attention to the storage period before the wastes go on to the filter. That period should be such that we are not getting acid conditions in the wastes before they go on the filter. The fact that the acid-producing constituents will remain in solution until we get putrefactive conditions is important. Solids will settle out if we provide a proper detention period. This will relieve the load on the filter very much. If we can reduce the load on the creamery waste filters, we will get more economic operation of the filters. At Slater we had originally a cinder filter but that did not prove to be satisfactory, so we have replaced

it with crushed granite, 1 to $2^1/_2$ inches in size. This seems to be very satisfactory.

Mr. Stanley: I would like to ask about the load on these filters.

Mr. Galligan: We have a 1500-gallon storage well, and that irons out the question of the concentration of our wastes very well. We figure the loading on the filters in gallons per acre per day with the oxygen consumed value. We figure our oxygen consumed for wastes of a certain strength and certain quantity per acre.

Mr. Stanley: What if the depth is more than six feet?

Mr. Galligan: That is the point that we do not know about. Some say that to increase the depth of the filter is an economic thing to do for it produces better nitrification in the effluent. I think the depth should be such that you get good filtration, and we have been trying different depths to see what is the most economic in regard to depth and size of stones, etc. Beet-sugar wastes are somewhat comparable to creamery wastes and it was found that there was some reduction in B. O. D. in the deeper filters, and that perhaps you would not get the nitrification in the shallow filters that you would in the deeper filters.

Mr. Wieters: The creamery in a small town presents a real problem. In the larger city the domestic sewage will absorb it. In some small towns the creameries have to be shut off from the general sewer. There are any number of small plants that do not function properly just because of the creameries.

Mr. Boyce: I wonder if the same thing happens here as it often does in Kansas creameries. If something goes wrong at the creamery and they spoil some product they empty great quantities of milk into the sewer and the concentration runs very high on account of creamery wastes for a while. Then an 85 per cent reduction in B. O. D. would still leave it pretty high in B. O. D. I wonder if there are cities that prohibit the discharge of milk into the sewers?

Operator: We have often been troubled with the creamery discharging a great supply of buttermilk at one time. Ordinarily they store this buttermilk in a large vat and farmers come in and get it for feed, but when the weather is hottest, and the farmers are the busiest, they do not come for it and so every few days the creamery will discharge a great quantity of the buttermilk into the sewer.

Mr. Boyce: We need to provide for such things. There would be some advantage in a longer storage period. It would iron out the fluctuation in concentration. We are concerned mainly with removing the acid from the waste so it can be handled in the sewage plant. Of course, in an activated-sludge plant that is different. We find in treating creamery waste we may get a high degree of purification and reduction of B. O. D., but the odors are terrible. The activated-sludge treatment is not suited to cream-

ery waste. I know of one place where they have a $30,000 plant to treat the creamery wastes and the odor is noticeable ten miles away. The waste showed a B. O. D. of 400 to 4000, or what would be normal for a city of about 180,000. It was a load that the sludge plant could not handle.

Mr. Warrick: We tried an activated-sludge plant at DeForest. We had not been operating it more than two weeks when someone dropped some cleaning powder in the sewer from the creamery. It just turned things all wrong and we had to clean out the whole system. The health officer came down to see what we were trying to do, and people complained to the state board of health.

Mr. Currie: We have had similar experience with packing-house waste. Something may go wrong in one of the plants, and the result will be that it is soon felt all over the sewage disposal plant, and very often we find that we lose our activated sludge that it has taken weeks to build up.

Mr. Hall, Centerville: We have had that same trouble that Mr. Boyce mentioned; the creamery takes care of its surplus by emptying it into the sewer. They have tried drying the buttermilk and that helps. But they have used some kind of washing compound that fills up the sewers with a white deposit, and we often have to clean out the entire system.

Mr. Wieters: If you alternate the condition of having oxygen in the sewer at some times and no oxygen at other times there will be an antagonistic condition. We are pretty sure that if you keep oxygen there all the time you will get organic growths that will clog up the plant and the whole system. Is the waste being treated before it enters the sewer?

Mr. Hall: Just drying the buttermilk. The material that clogs the sewers is a white solid that looks like lime.

Operator: Mr. Hall mentioned the buttermilk drier. This, of course, takes care of the buttermilk, but have any of you had any trouble with odors? Under some atmospheric conditions the odor is very bad, and unless the creamery is in a rather isolated location there will be much complaint.

Mr. Warrick: We have had a marked tendency on the part of creameries and cheese factories to install driers and make use of the removed solids. According to some of the dairy officials with whom I have talked they have found commercial value in these solids that makes it worth while to save them. They have had no trouble with the local authorities on account of the driers being used. In the small communities they are willing to put up with a certain amount of atmospheric nuisance because the surrounding population is rather dependent upon the creamery.

Operator: We have a small town of about 1800 population and are having considerable trouble with our disposal plant. We have a large creamery that produces two million pounds of butter a year, and the waste

is taken care of at the municipal plant. Is it practical to try to care for that waste in the municipal plant?

Mr. Wieters: I would say that under those circumstances it would be much better to have some type of a separate plant for the creamery wastes.

Mr. Warrick: As a rough estimate I would say that you can dispose of creamery wastes to the extent of about twenty per cent of the total sewage flow. If the volume is greater than that you are apt to have trouble.

Operator: At the present time we have a flow of about one hundred gallons per minute, and the creamery uses from one-third to one-fourth of the water supply. We have the old style of Imhoff settling tank. The detention period is about one hour.

Mr. Currie: It occurs to me that it might be possible to handle more creamery wastes in the sewage treatment plant if the flow could be equalized, so that it would flow into the city system at a uniform rate. Then there would be a more uniform concentration of creamery wastes with domestic wastes. However, if the wastes were to be held at the plant and allowed to flow more equally, it would be necessary to prevent decomposition of the waste before it entered the system. It would probably be necessary to chlorinate the wastes. Any city treatment plant could absorb more if the wastes came in a more uniform flow. It is the percentage of B. O. D. removal that is important, not just the amount. If you have a sewage containing 800 to 900 parts per million B. O. D. and you remove 25 to 30 per cent of it you still have more left than if you had 200 to 250 to begin with.

Mr. Galligan: I think the trouble with creamery wastes is not so much the strength of the B. O. D. as the acidity. The equalizing tank would still leave that problem.

Mr. Currie: In the particular instance to which I was referring it was not the acid that was causing the trouble. The wastes reached the plant while they were still fresh enough so there was little acid. It was a case of overloading the plant and flowing too fast on to the filters.

Mr. Wieters: What was the pH at this plant?

Engineer: It was sometimes down as low as 4.5 or 4.6.

Mr. Wieters: I think there are less objectionable odors in connection with these coöperative creameries than with the large creameries that buy all sorts of cream. The coöperatives usually try to produce a good quality product and receive only cream that is in good condition. The others may accept cream that is old and the drying creates more of a nuisance. In most of the coöperative creameries the farmers will put in driers if they see that it will make more money for them. The alkaline substances used in washing helps to neutralize the acids in the wastes.

The Treatment of Sewage Containing Industrial Wastes[1]

BY ROY S. LANPHEAR[2]

Much has been written concerning the treatment of industrial waste liquors, but the data presented usually fail to demonstrate how to handle these wastes when they are present in varying amounts in large quantities of sewage. As a rule, such information has been obtained in the treatment of small quantities of a single industrial waste. Frequently the method developed will not lend itself to the economical or effective operation of a large municipal sewage treatment plant.

A successful method for treatment of municipal sewage containing variable quantities of a number of industrial wastes may be demonstrated by experiments made on a large scale with the sewage to be treated. The operation of municipal experimental sewage treatment plants serves this purpose. Successful large plant operation, based upon the results obtained by operation of the experimental plant, is dependent upon two factors, namely, prompt construction of the large plant and control of the discharge of industrial wastes into the sewers.

To a person not intimately connected with sewage plant operation, control of the discharge of industrial wastes may not seem very difficult. Those familiar with this problem realize that such control may be difficult. Undoubtedly, there are many instances of coöperation between industry and the municipality. As a rule, however, such coöperation is usually found in the case of a single industry, with a small amount of waste liquor, to whom the order to cease stream pollution applies solely.

Coöperation between industry and municipality in the treatment of industrial wastes or control of their discharge into the sewers is necessary. Possibly because of my own experience with acid-iron wastes, I am particularly interested in the results obtained at the sewage treatment plants at Fostoria, Ohio, and the southerly plant at Cleveland, Ohio. The Fostoria trickling filters became so clogged with hydrate of iron that their operation was impossible; operation of the Cleveland trickling filters was suspended until the quantity of iron wastes was regulated, for fear of the same result. The difficulties of the sewage treatment plant at Akron, Ohio, in successfully treating the wastes of the rubber industry have recently been reported. If I am informed correctly, the design of this plant was based upon the assurance that these wastes would be properly cared for before they were discharged into the sewers. Irrespective of the particular waste liquor, the quantity and its distribution in the sewage during the

[1] *Presented before North Carolina Sewage Works Association, Hendersonville, N. C., October 15, 1930.*

[2] *Supervising Chemist, Sewer Department, Worcester, Mass.*

twenty-four-hour period are vital factors in the successful operation of a municipal sewage treatment plant.

Sometimes the combination of two industrial wastes in the sewage results in increased difficulties of operation. The proper control of the quantities of these wastes may sometimes be advantageous. Maintenance of proper control is theoretically possible with perfect coöperation; otherwise convenience of operation of industry becomes the controlling factor, even though plant operation is made more difficult. Lack of effective municipal ordinances, precedent and politics, any one or all three, may result in placing a burden upon the municipal sewage treatment plant in the handling of industrial wastes which vitally affect its efficiency and period of operation.

A directory of manufacturing establishments in Worcester, Massachusetts, recently compiled by the industrial bureau of the Chamber of Commerce, contains the names of about 2600 plants, which employ about 35,000 workers, who receive almost $50,000,000 in wages annually. The total value of the products averages more than $200,000,000 yearly. These plants represent a total capital investment of approximately $190,000,000.

The industrial wastes in the sewage of the City of Worcester with which the sewage treatment plant must contend include foundry sand, spent dye liquors, oil and grease, spent acid or ferrous sulphate from the wire industry and lime wastes from a large tannery. The last two wastes are present in such large quantities as to make the presence of all others seem small in comparison. The accumulation of grease is greatly increased following storms, some 35 per cent of the sewer system being on the combined plan.

Foundry sand tends to pass through the grit chambers and is found in the side channels of the Imhoff tanks. In the old plant, the sand was found in the settling tanks. The proper place to intercept such material is at its source so that it will not wash into the sewers. No Imhoff tanks have been cleaned out; therefore, the quantity and effect of this material in the sludge compartments has not been ascertained.

Dye liquors color the Imhoff tank effluent. Trickling filters ten feet deep, operating at a rate of 1.5 million gallons per acre per day, remove this color.

Oil and grease are the wastes most difficult to handle. When such wastes are present the appearance of the surface of the sewage in the Imhoff tanks or in the settling tanks is unsightly. To maintain a clear appearance of the sewage in a large plant is a considerable expense, yet the plant visitor little realizes this and goes away with an unfavorable impression, even though the remainder of the plant be of excellent appearance.

Much of the grease in Worcester sewage comes from a slaughter house and a tannery. Fortunately, most of this material passes to the end of the

influent channel of the Imhoff tanks and enters the last two sedimentation compartments of the last tank in each battery. Here it is cleaned of much sewage matter by using a water stream under considerable pressure, removed twice each month with perforated skimmers and carried by water in a trough and pipe line to small sand beds. Excessive accumulation of grease on the sewage in these two tanks is one source of odor from the Imhoff tanks. The second source of odor will be mentioned later. Control of the odor nuisance due to grease is merely one of dollars and cents. The remaining ten tanks are cleaned only once or twice a year by running the surface water into the last tank of the battery, by way of the effluent channels.

Approximately twice a year the grease on the sand beds is burned. There is some smoke nuisance, which persists for only a few hours. These beds are unsightly and ultimately some improvement will be made in the disposal of grease. A local rendering company carried away the grease only one day and claimed injury to its product. The yearly removal of skimmings amounts to from 9000 to 10,000 cubic feet and costs about $500. While the appearance of the tanks is not so good as desired, the improvement is commensurate with the cost.

The lime wastes from the tannery are the source of the second disagreeable odor which can be detected at certain times at the Imhoff tanks. These wastes, like the iron wastes, are received in so-called doses. The odor is carried by the Imhoff tank effluent to the dosing tanks and to the nozzles of the trickling filters.

The lime wastes and acid iron-pickling wastes present a difficult operating problem owing to precipitation of the iron in the sewers or the Imhoff tanks and consequent increase in sludge accumulation. This condition does not directly affect the appearance of the tanks in normal operation and is noticeable only at certain times. It entirely escapes the casual observer.

Sludge must be drawn frequently and in large quantities in order that the Imhoff tanks may operate efficiently for clarification of sewage. Until the present business depression, it has been necessary to draw from 1.5 to 2.0 million gallons of sludge, containing from 6 to 7 per cent dry solids, during each month, except the first two, since the plant was placed in operation. During June and July, 1930, the quantity decreased to 1.35 million gallons each month and in August to 0.5 million gallon; the percentage dry solids increased to 7.6. This sludge is dried upon the drying beds during the summer season and drawn into a lagoon during the winter.

It is apparent that the presence of these two industrial wastes in the sewage places an abnormal load upon the sludge compartments of the tanks. Close attention is required to maintain a maximum amount of sludge in the lower compartments without fouling the slots. Precipita-

tion of iron does not always take place. Under such conditions efficient sedimentation of the floc does not occur, resulting in a tank effluent which contains an excessive quantity of suspended solids.

The iron (Fe) content of the sewage, in monthly averages of composite samples, varies from 35 to 70 parts per million; a maximum of 110 has been obtained. The yearly average varies from 50 to 60 parts per million. The iron content of separate doses commonly varies from 125 to 250 parts per million, while a maximum quantity of 1302 parts per million was treated in a 70-minute period at the old plant.

The presence of the lime and iron wastes in the sewage apparently has no serious ill effect upon the digestion of sludge in the Imhoff tanks during the summer season. While the pH value of the sewage varies widely and rapidly, as, for example, from 3.2 to 9.6 within 30 minutes, the fresh sludge generally has a pH value of 6.6 to 6.8 and the digested sludge, 6.8 or 6.9. Sludge having a maximum organic content of 55 per cent has been drawn during the late winter months, a condition which is probably due, to a great extent, to the low temperature prevailing in the digestion compartments.

If either one of these major industrial wastes were to be removed from the sewage, the effect upon Imhoff tank operation would be problematical. Reduction of quantity of both wastes, but maintenance of a constant average pH value in the sewage, should result in a better tank effluent, much less sludge to care for and the probability of more thoroughly digested sludge.

The Imhoff tank effluent, which is treated by trickling filters, generally contains from 25 to 50 parts per million of iron (Fe), the yearly average varying from 30 to 35 parts. During five years of filter operation there have been no evidences of abnormal clogging of the filter material. Analyses indicate a reduction of about 25 per cent of iron and an apparent storage in the filters. It is difficult to obtain a fair sample of the filter effluent, on account of its large content of suspended iron floc. This is especially true during unloading periods. My opinion is that storage of iron is not so great as analysis seems to indicate. A storage of from 7 to 8 parts per million of iron each year for five years represents from 70 to 80 tons of iron per acre of filter.

If the lime wastes were not present in the sewage, what effect would the doses of acid iron wastes have upon the efficiency of the trickling filters? Experimental trickling filters of small-sized stone were successfully operated from 1911 to 1913, treating an Imhoff tank effluent containing an average of about 31 parts per million of iron. At that time there were no lime wastes in the sewage. The reduction of iron averaged 60 per cent. The experimental filters treated about one-third more tank effluent per unit area than the plant filters, with equally as good nitrification as that ob-

tained in the present plant, until the summer of 1930. There is no reason to believe that the efficiency of the filters in the present plant would be seriously affected if the lime wastes were removed from the sewage.

Elimination or material reduction of the quantity of these major wastes, as represented by Sunday samples, has resulted in a marked increase of the nitrate content of the filter effluent. It is interesting to note that under operating conditions of the past summer (1930), this 50 per cent increase of nitrates has been reduced one-half or less and that results equal to the former Sunday results have been obtained on week-days during much of the time. The average pH value of the filter influent has dropped from 6.8 to 6.6 and the rate of filter operation has been almost the same as during the summer of 1929.

The quantity of sludge from the final settling tanks is greatly increased by precipitation of iron in the filters. The sludge is pumped to drying beds, where the solids settle rapidly, leaving a large amount of water on top which must evaporate before the sludge will dry. Accumulation of sludge in the Imhoff tanks under normal conditions is sufficiently rapid to preclude any attempt to pump humus sludge into these tanks.

Air drying of an excessive accumulation of sludge from final settling tanks presents an operation problem which requires as an essential of success the drawing of a concentrated sludge to the drying beds. Sufficient drying-bed area must be provided to keep the final settling tanks reasonably free from sludge. If sludge is drawn too deeply on a drying bed, odors may become a source of nuisance. The dried sludge must be removed from the beds at the earliest possible moment, for, if this is not done, the dry top sludge will blow about the plant and become a nuisance and actual removal of the sludge will become very disagreeable work.

Operation of sewage treatment plants generally suggests alterations or additions which improve results of sewage treatment, make for greater ease of operation, keep down maintenance cost and, in some instances, actually reduce operation costs. Such possibilities usually occur in large plants treating sewage containing industrial wastes.

Industrial wastes in Worcester sewage place a heavy load upon the sewage treatment plant which is being successfully handled. The final effluent is completely stable except during a period of about ten weeks in mid-winter. The cost of plant operation, exclusive of any fixed charges, amounts to about 26 cents per capita per year. It is very difficult to determine the increased expense of plant operation due to the industrial wastes contained in the sewage. Sludge disposal in 1929 costs approximately $15,000 or nearly 30 per cent of the entire operating expense. It is pleasing to note that present operating results indicate no permanent plant deterioration due to the industrial wastes now in the sewage.

There is a tendency, in the construction of medium and small municipal

sewage treatment plants, to adopt the settling tank and separate sludge-digestion method of treatment. Where a final plant effluent of excellent quality is desired the activated-sludge method of sewage treatment is much favored. For that reason a brief statement of the results of activated-sludge treatment of Worcester sewage, with its large industrial waste content, may be of particular interest.

An experimental plant, treating from 75,000 to 125,000 gallons of sewage per 24 hours, was operated from July 6, 1917, to August 15, 1918. The excessive doses of lime wastes were not in the sewage at that time. The iron (Fe) content of weekly and monthly composite samples of sewage varied from 21.8 to 62.3 parts per million, the general range being from 45 to 55 parts per million.

The nitrogen as nitrate content of the effluent never exceeded 0.84 part per million. When sufficient quantities of air were used, together with suitable periods of aeration, the effluent was colorless, almost completely stable and contained from 2.5 to 7.0 parts per million of iron. The suspended solids content of the effluent usually varied from 15 to 40 parts per million and never exceeded 81 parts. Stability of effluent was obtained by oxidation of the soluble and suspended organic matters in the sewage and excellent clarification of the aerated sewage. The reductions of soluble and suspended organic matters, based on albuminoid ammonia determinations, were greater than 70 and 90 per cent, respectively. Sewage of average strength was treated with 5 cubic feet of free air per gallon; the sewage was aerated 6.3 hours; the sludge was re-aerated 5.1 hours and 27.4 per cent of sludge was returned to sewage when the best results were obtained.

A report upon the operation of the plant was made in 1919 by the writer, upon his return to the department, which contained the following statement: "If an average stability (referring to the effluent) greater than 90 per cent is desired, the results of operation indicate that strong sewage will have to be aerated at least 6.5 hours with a total quantity of about 4 cubic feet of free air per gallon, the sludge re-aerated for about 6 hours and the quantity returned to the sewage should be slightly more than 25 per cent of the sewage flow."

An interesting condition noticed when the effluent was very well clarified, but the organic content of the sewage had not been sufficiently reduced owing to inadequate treatment, was the appearance of colored and turbid effluents. Such conditions were due to doses of industrial wastes contained in the sewage.

According to the prevailing conditions at that time the present method of treatment was selected because of its efficiency and much lower estimated cost of operation, as compared with the activated-sludge method.

The sewage treatment plant at Worcester is operated under the direction

of the Superintendent of Sewers, Mr. John H. Brooks, Jr. The writer has been in immediate charge of sewage treatment for some years.

Effect of Industrial Wastes on the Operation of Municipal Sewage Treatment Plants[1]

Mr. Sherman Chase: Mr. Chase of Metcalf & Eddy, Boston, Mass., stated that a rubber-reclaiming plant at Akron, Ohio, discharged industrial wastes, consisting largely of cellulose, into the municipal sewers so that 50 tons of solids on a dry basis reached the treatment plant each day, whereas the design of the tanks allowed for 25 tons of solids on a dry basis. This serious overloading of a sewage treatment plant costing $1,800,000 was remedied by treatment of the industrial wastes.

Mr. Chase also stated that at Fostoria, Ohio, with a population of 12,000 and a sewage flow of 1.5 to 2.0 m. g. d., the sewage treatment plant, consisting of Imhoff tanks and trickling filters, was out of commission because of the discharge of acid iron wastes from a wire mill and carbon breeze from a carbon company in the city. The digestion chamber of the Imhoff tanks became filled with inorganic solids, which prevented the digestion of the sewage solids. The tank effluent contained iron, which precipitated on the trickling filter and solidified into a hard film containing 25 or 30 per cent iron. Consulting engineers concluded that three remedies were possible: (1) for the city to build an independent waste treatment plant; (2) for the city to pass ordinances requiring separate treatment of industrial wastes; (3) for the exclusion of industrial wastes from the sanitary sewers. The second procedure was adopted. The carbon company has enlarged existing sedimentation tanks to improve the removal of carbon from its wastes, and the wire mill has built a large storage reservoir for sedimentation purposes.

Mr. H. H. Wagenhals: Mr. Wagenhals briefly noted the serious interference with sewage treatment at Gloversville, due to the discharge of oil from tanneries in the city.

Mr. C. R. Cox: The serious effect of the discharge of about 50,000 gallons of wastes per day from three canneries in the village of Holley, N. Y., was discussed. These industrial wastes increased the B. O. D. of the influent to eight times the average B. O. D. of domestic sewage, thus increasing about eight times the load on the treatment plant which was designed for a population of 2280, or about $^1/_8$ the actual equivalent population represented by the industrial wastes.

A similar experience at Fredonia, N. Y., indicated that the discharge

[1] *Round Table Discussion at the Second Annual Meeting of the New York State Sewage Works Association, Albany, N. Y., May 10, 1930.*

of 130,000 gallons of cannery wastes per day was equivalent to 1,600,000 gallons of sewage, which is 2.8 times the actual sewage flow. This sewage treatment plant, therefore, receives during the summer months about three times the anticipated loading.

Mr. H. B. Cleveland: Mr. Cleveland emphasized the importance of municipalities retaining the services of the designing engineer to help solve operating difficulties. He expressed the opinion that it is best for the municipality to treat a mixture of sewage and industrial wastes rather than to require the separate treatment of industrial wastes. Mr. Sherman Chase expressed the opinion, however, that each case should be solved on its own merits and that city ordinances should be passed to permit the exclusion of harmful industrial wastes from municipal sewers, if deemed advisable.

Mr. Isadore Mendelsohn: Mr. Mendelsohn also emphasized the importance of retaining the services of the consulting engineers to help solve operating problems and that such was being required by many state departments of health when plans for sewage treatment plants were approved. He also indicated that it is feasible to charge the industry for the increased cost of operation of municipal sewage treatment plants incidental to the discharge of industrial wastes into the sewers.

Mr. C. A. Holmquist: Mr. Holmquist stated that sewer rental laws may be extended to cover the cost of treatment of industrial wastes, whereby industries would be taxed separately for any undue burden imposed upon municipal sewage treatment plants.

Garage Wastes[1]

BY JOHN F. SKINNER[2]

Everybody knows the problem. Every city and village has it. Laws and ordinances are few.

The speaker had occasion to inquire what law or regulation of the State or State Health Department could be invoked to keep fuel oil, machine shop and garage wastes out of a new village sewage disposal plant.

Mr. Holmquist answered under date of January 31, 1930: "There is no specific regulation covering the discharge of such wastes into sewer systems or disposal plants." He indicated that control would have to be effected under the Health Commissioner's permit "that only sanitary or domestic sewage shall be admitted to the proposed sewage treatment works."

The City of Rochester has no ordinance prohibiting the discharge of such wastes into the sewers, provided the sewers are not obstructed or damaged.

In the 80's a naphtha pipe line from the Vacuum Oil plant to a gas company's plant in Rochester was broken under the Pennsylvania Railway tracks and discharged into a sewer, which blew up about a mile and a half down stream. Two stone mills were burned and two men killed.

A few years ago a large tank was constructed below ground of cement blocks, with the intention of holding heavy road oil. The oil leaked into the ground, into the sanitary sewers and eventually found its way to the Brighton District sewage disposal plant. Fortunately, it did not reach the trickling filters, but settled into the sludge compartments of the Imhoff tank, putting it out of business for six months, as all sludge had to be drawn and the tanks re-seeded. Several miles of sewers also had to be flushed out from manhole to manhole.

It is not uncommon to see oily waste on the surface of primary tanks. When this is gray in color, entangles fecal wastes and gives off the fetid odor of undigested sludge, it may cause a nuisance depending upon the exposure. Skimming and hosing and efficient scum boards are then necessary. Where fine garbage is also found in this floating matter, a fine screen ahead of the tank is indicated. Plants at Batavia and East Rochester have been troubled in this manner. At Batavia garbage has appeared in the scum. At East Rochester this is obviated by a revolving screen.

A survey of conditions has been made in Washington, D. C. The original report is dated November 18, 1928, and is signed by J. B. Gordon, Sanitary Engineer. Conclusions are drawn from this in a report of the

[1] *Round Table Discussion, New York State Sewage Works Association, September 13, 1930.*

[2] *Sanitary Engineer, City of Rochester, N. Y.*

engineering department dated February 25, 1929. The following figures for the year 1928 do not include automobiles owned and operated by the District of Columbia or the U. S. Government:

Motor vehicle licenses issued	150,522
Motor vehicle in use (approximate)	119,200
Estimated gallons of crank case oil each	16.4
Estimated gallons of crank case oil each withdrawn	6.3
Estimated gallons of crank case oil waste	752,000

About 43 per cent of the owners have expressed a desire for free collection of waste oil.

The U. S. Bureau of Standards has reported that recovered oil may be re-refined and rendered as good as new. It may be used anywhere that oil of like viscosity is required. Various processes of recovery are in use, including cleansing earth, chemical compounds, centrifuging and distillation.

Forty-six cities replied to a questionnaire sent out by the City of Washington and are quoted in the report. The replies indicated that 70 per cent of the cities have prohibitive ordinances, 65 per cent have trouble from oil in sewers, 50 per cent allow commercial concerns to collect, in part, 35 per cent have had explosions and fires, and 7 per cent have instituted collection of oil.

Answers of the nine following cities may be cited:

Toronto—Collection by the five largest oil companies.

Winnipeg—Waste is stored in small drums and removed by the oil companies.

Copenhagen—Gasoline is separate from the oil.

Paris—Oils are distilled and re-used.

Baltimore—Waste oil is collected by contract.

Boston—Reports are filed when accidents occur.

Milwaukee—Collections are made in tank wagons and garbage is burned with the oil. Ordinances to keep oil out of sewers are non-enforceable.

Syracuse—Accumulations at the treatment plant cause difficulties.

Rochester—Waste oil collected is used at the airport in laying dust.

The following are suggested uses for oil wastes: burning dumps of garbage and refuse, fuel oil, mosquito control, road oil and re-refining for lubricating oil.

One man suggests combining this problem with that of the disposal of abandoned motor vehicles. He would provide a derrick truck, lift old automobile bodies on to the road, run over them and flatten them with a tractor, hoist them on to a truck and transport them to the point of disposal where they will be sheared into sizes which may be received by an oil-fired furnace. When melted down, window weights or other rough castings will be the final product. This project has the merit of making

the waste oil of the present machines reduce the wrecks of the preceding generation instead of leaving them to posterity.

If collection of wastes is made it should preferably be performed by the municipality, for, if by contract, the larger places will be served and the smaller sources may be neglected. Although more expensive to handle, the smaller places, in the aggregate, account for a large amount of waste.

The following is suggested as a logical, reasonable and economical solution:

First, provide ordinances requiring that such dangerous and troublesome waste be kept out of sewers and disposal plants, and prohibiting the connection of garage pits to the sewers.

Second, have the municipality collect free and without payment to the owner all waste (not otherwise removed) by sucking into tank wagons at reasonable intervals.

Third, provide that the waste thus collected becomes the property of the municipality to be disposed of in the most profitable manner, depending upon local conditions.

In many cases, this service will pay for itself.

Separation of Oil from Waste Waters by an Electrical Method. F. J. BOWERS, S. J. LATHROP AND W. POLATSIK. U. S. P. 1,746,964; *Chem. Zbl.*, 1930, **2**, 2556. Fatty matter was easily separated from the surface of the waste water in a thick coherent layer and was passed through an apparatus consisting of a series of pipes. In these pipes were inserted copper rods serving as anodes and cathodes. When a current was passed through the apparatus the oil immediately began to separate on the anodes.—Abs. No. **346**, *British Summary of Current Literature, Water Pollution Research*, Vol. IV, 3 (March, 1931).

Garage Wastes[1]

BY EDWARD WRIGHT[2]

This has always been a timely subject in the Boston Metropolitan District, especially since June 1, 1914, when the East Boston sewage pumping station of the Metropolitan District Commission was destroyed by an explosion of gasoline, resulting in the death of six men and the serious injury of at least three others.

The investigation of this disaster, carried on largely by Mr. H. W. Clark, Chemist of the Department of Public Health, showed that explosive mixtures were present in the air in the sewers tributary to this pumping station, especially in the main sewer from East Boston, where there was then a large oil storage plant.

This explosion is described in the *Engineering Record* of November 21, 1914, and the investigation as to the explosive mixtures was described in the *Engineering Record* of December 5, 1914. Of 22 samples of sewer air taken from an elevation just above the flow line, in various manholes on the sewer lines tributary to this pumping station, various explosive mixtures were found. All of the samples from the East Boston Metropolitan sewer, with two exceptions, were highly explosive.

As a result of this disaster the pumping station was reconstructed and a system of forced ventilation installed, but perhaps the more important result was the adoption of rules and regulations by the Massachusetts Department of Public Safety, the Metropolitan District Commission and the Department of Public Works of the city of Boston relative to the establishment of suitable traps on the sewer lines from all garages and other establishments where gasoline is used.

Section 26 of the Massachusetts Department of Public Safety rules and regulations, as found in Form X, requires the installation of traps having a storage capacity of at least 35 cubic feet, with an outlet extending from a point two feet above the bottom of the trap and a water seal of not less than two feet. The outlet pipe is required to be properly ventilated to prevent siphonage. The sump below the entrance to the outlet pipe is for catching sand and grit, and it is required that the basins or traps shall be freely ventilated by connection with the outer air. The regulation provides that the traps or basins can be made of metal or masonry and they can be placed either inside or outside the building. Another requirement provides for frequent cleaning and for the disposal of grease and oil in a safe manner. The penalty is a revocation of the garage license.

Drawings for gasoline and sand traps can be obtained from the Public

[1] *Read at New England Sewage Works Association, October 15, 1930, Fitchburg, Mass.*

[2] *Associate Sanitary Engineer, Massachusetts Department of Public Health.*

Works Department of the City of Boston, Sewer Service Division. Those for garages containing ten or less automobiles have a diameter of 3.5 feet and a depth below the flow line of 4.33 feet, while those for garages containing more than ten automobiles are 5.67 feet by 6.33 feet in plan over-all, with a depth below the flow line of 6 feet. These latter traps are provided with a baffle on the inlet end with a clear opening of 2.67 feet on the bottom.

Another state requirement is in the standard rules and regulations for plumbing, Section 8, which provides that every building in which gasoline, naphtha or other inflammable compounds are used for business purposes shall be provided with a special trap or separator, so designed as to prevent the passage of oils or gases into the sewer, and shall be ventilated with a separate pipe to a point 3 feet above the roof. The waste of every washstand for vehicles shall be provided with catch basin so designed that sand cannot pass into the drain.

While these latter rules and regulations have been adopted in most of the cities and larger towns of the state, they have not been adopted in the smaller towns because there is no state law requiring standard rules and regulations on plumbing except on request of the municipality. One hundred and three municipalities have adopted plumbing rules and regulations. The rules in each instance require approval by the State Department of Public Health, and the standard rules have recently been approved for several municipalities.

The danger of discharging lighter volatile oil into the sewers, whether the sewage is treated or disposed of by dilution, is obvious. Comparatively little difficulty has been experienced in this state with oily wastes at sewage disposal works other than at Moon Island, Worcester and Fitchburg, with traces of oil now and then at Framingham and Spencer. It does not appear to have been the problem that it has been in some of the California sewage disposal works, such as the plant at Pasadena, which the writer visited a year ago. Here the sewage was entirely covered with a thick film of heavy oil and a skimming basin was then being designed to remove the oil.

Mr. John F. Skinner, Sanitary Engineer of Rochester, N. Y., in his article at the Fall Meeting of the New York State Sewage Works Association, makes reference to various uses of spent crank-case oil, such as in burning garbage and refuse at dumps, as road oil and—after refining—as use for fuel oil. So far as the writer's knowledge is concerned, no such general use has been made in Massachusetts. Mr. Skinner also refers to the use of this oil for mosquito control work. This has been tried in many places but with comparatively little success, for certain reasons, particularly because no suitable storage plants have been provided, with the result that when the demand was greatest there was no supply, and more particularly because of the fact that crank-case oil is rather too heavy to be used with much success

for this purpose. In New Jersey, however, considerable use has been made of spent crank-case oil in mosquito control work, provision having been made for storing this oil and for cutting it with lighter oil. In at least one instance it is collected by a large oil company, cleaned and used for this purpose.

Solving the Oil Waste Problem of a Large Machine Shop. G. W. WOODS. The Hughes Tool Company of Houston, Texas, has had the problem of disposing of a cutting fluid prepared from one volume of oil and eight volumes of water. The oil emulsion is used for cooling and lubricating cutting tools. It becomes contaminated with metal particles and organic matter, which cause it to become rancid.

For a number of years the emulsion was discharged into a bayou; later, into the city sewers. The waste caused serious trouble at the Houston activated-sludge plant. By coöperative work between the Hughes Tool Company and Mr. W. S. Stanley, chemist at the sewage treatment plant, a method was found for clarifying the waste. About 1000 gallons of the waste are pumped into a rectangular tank and treated with 10 to 15 pounds of hydrated lime. The mixture is agitated by means of air blown through perforated pipes at the bottom of the tank. Next a solution of 25 pounds of aluminum sulphate in 25 gallons of water is fed into the tank, with continuous aeration, for about 15 minutes. In a short time the oil separates and, with a part of the aluminum hydroxide precipitate, floats to the surface. The remainder of the floc sinks to the bottom of the tank. The oily surface floc is drawn off and allowed to stand until the separated oil can be burned. It may be possible to recover the oil by heating it and filtering out the soaps and insoluble particles. If the oil can be reclaimed the saving will more than pay for the cost of the disposal of the cutting compound.

The settled floc and the supernatant liquid, below the surface scum, are drawn off and drained on a sand filter. The effluent is discharged into the city sewer.—*Municipal Sanitation*, **1**, 397 (July, 1930).

Editorial

Activated-Sludge Research at Milwaukee and London

Investigations of different phases of the activated-sludge process have recently been made at Milwaukee and London, the results of which have been published in journals not ordinarily available to the American sanitary engineer. Fairly complete abstracts of both papers appear in this issue (pages 321 and 315). Although somewhat different in scope, both investigations included, among other objectives, a study of means for shortening the time required for aeration of sewage in the activated-sludge process.

In the Milwaukee experiments the investigators claim they have discovered the active biological agents responsible for clarification and stabilization of sewage. They infer that, by the cultivation of these organisms (protozoa), it may be possible to introduce cultures into sludge as needed and thus to speed up the process, or at least to maintain maximum efficiency at all times.

In the London experiments, the well-known Haworth paddle-wheel-channel method of mechanical aeration was modified by the addition of a little air and by reaeration of sludge, and it was believed that these changes were responsible for accelerating the rate of treatment from 120,000 to 300,000 gallons per day. Diffused-air tests indicated to the author that only 80,000 gallons could be treated per day. The comparison was stated to be on the basis of equal tank capacity for the treatment of settled sewage. One must therefore infer that the improvement effected, as described briefly in the abstract, resulted in an almost four-fold increase in capacity or, inversely, in reducing the detention period to about one-fourth that required with diffused-air aeration. This is an astonishing claim, unsupported by adequate data. Further information is certainly necessary to make these claims convincing.

Mr. Cramer's work at Milwaukee was undertaken in collaboration with Dr. John Arthur Wilson, who has also published a brief reference to the results of the work on protozoa (*Industrial and Engineering Chemistry*, **23,** 442 (April, 1931)). Dr. Wilson and Mr. Cramer formerly considered the mechanism of purification by activated sludge to be primarily chemical. On the basis of previous experimental work, they stated, in 1928, that it was generally thought that bacteria, or other living organisms, are essential to the building-up of activated sludge, but that experiments conducted at the Milwaukee plant indicated otherwise. The experiments

seemed to prove to them at that time that the action was not a biological but a chemical one, involving oxidation. Now, on the basis of more recent work, Mr. Cramer concludes that protozoa are the effective agents in the action of activated sludge, and Dr. Wilson states that this is the first time that protozoa have been shown to be responsible for purification by the activated-sludge process.

As yet only the results of laboratory-scale experiments have been reported, but it is understood that larger-scale experiments were made. It is to be hoped that the results of these experiments may soon be published in order that other investigators may learn whether more evidence has been accumulated to substantiate the new theory than the results of the semi-qualitative experiments described in Mr. Cramer's paper. Analyses of sewages and effluents were not reported, results being stated rather loosely as "caused clarification," "neither clarified nor became septic" and "clarified in 10 days." These criteria are hardly as convincing as actual analyses of the various effluents.

Dr. Ardern has reported the results of carefully controlled experiments on the rôle of protozoa in activated sludge, and concluded that protozoa play no important part in the process of purification, although he thought it possible that they facilitate the production of a more highly clarified effluent. Other investigators have usually reached the same conclusions as Dr. Ardern.

In view of this divergence of opinion, it is clear that further investigation is necessary before the most recent Milwaukee theory can be accepted. If it can be shown experimentally, however, that the addition of protozoa from culture tanks results in more rapid purification, as compared with control tests in which the same amounts of sludge are used without artificial cultivation of protozoa, the results may have practical significance. It must also be demonstrated whether or not it will be possible to settle the inoculated sludge in the final settling tanks.

The use of larger amounts of solids in the aeration tanks results in more rapid purification, as was shown by Harris, Cockburn and Anderson, some years ago, but this result does not necessarily indicate that increased numbers of protozoa are responsible for the more rapid purification, as suggested by Dr. Wilson, but may also be ascribed to increased numbers of bacteria or to increased surfaces of the sludge flocs.

The results so far reported from Milwaukee are of great interest to other investigators and will undoubtedly lead to research at other places in an attempt to derive practical benefits from the Milwaukee observations.

The London work has been reported with no accompanying data, but one of the collaborators would have us believe that such data might have obscured the "Gallic clarity" and continuity of the paper. This is rather a novel idea. Most readers would be willing to sacrifice a little of the

continuity and Gallic clarity if adequate and convincing analyses and operating results had been reported. The discussion of the paper indicates that all of the conclusions may not be accepted unreservedly in England.

German Sewage Works Association

A sewage works association is being organized in Germany by a group of the leading sanitary engineers of that country. An advance notice of this intention has been sent out by a committee, most of whose members are well known to American engineers and chemists engaged in sewage work. The committee consists of Messrs. Imhoff, Helbing, Prüss, Langbein, Mahr, Heilmann, Thumm, Krawinkel and Hanffstengel. The first seven are well known to sanitary engineers and chemists in America and the first four made an extended visit in this country two or three years ago. The list includes the leading engineers in sewage treatment work in Germany. The prestige of their names and reputations indicates that the association will be representative and successful.

The association will be organized primarily from the membership of the German Association for Construction Work (Bauwesen). Members of other German societies who may be engaged in sewage work must join as associate members.

The notice has been sent to engineers, chemists, physicians and city officials throughout Germany.

One of the aims of the association is to establish relations with foreign associations of similar character, with regard to exchange of information and, possibly, of publications.

This announcement is of interest to members of the American Federation of Sewage Works Associations as it indicates that there is appreciation in Germany of the need which led to the amalgamation of our various local sewage works associations into our National Federation. Further information regarding the progress of the German association will be of interest.

Proceedings of Local Associations

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Shimazaki, Takahiko
Tanaka, T.
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State School of Hygiene

Russia

Dumpe, I.
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Serbia

Prestini, Knjizara M.

Scotland

Harris, F. W.

South America

Aguirre, E. Edward
Altoberro, J. C.

Spain

Molinas, C.

Notice of Local Association Meetings

CENTRAL STATES SEWAGE WORKS ASSOCIATION. Hotel Loraine, Madison, Wisconsin. May 22–23, 1931. Proceedings in next issue.

MARYLAND-DELAWARE WATER AND SEWERAGE ASSOCIATION. Du Pont-Biltmore Hotel, Wilmington, Delaware. Meeting held May 5–6, 1931. Proceedings in next issue.

NEW ENGLAND SEWAGE WORKS ASSOCIATION. Hotel Bond, Hartford, Conn. Meeting held April 27, 1931. Proceedings in next issue.

OKLAHOMA WATER AND SEWAGE ASSOCIATION. Stillwater, Oklahoma. Meeting held April 19–24, 1931. Proceedings in next issue.

PENNSYLVANIA SEWAGE WORKS ASSOCIATION. State College, Pa. June 23–24, 1931.

New York State Sewage Works Association Third Annual Meeting

Albany, N. Y.

March 5, 1931

The Third Annual Meeting of the New York State Sewage Works Association was held in Albany, N. Y., March 5, 1931. Eighty members and guests were registered. At the business meeting W. P. Gyatt (Syracuse), C. A. Howell (Buffalo) and E. B. Phelps (New York) were elected to the Executive Committee to replace H. B. Cleveland, M. Cohn and G. D. Holmes whose terms of office expired. Mr. John F. Skinner of Rochester was elected president, and Professor E. B. Phelps of New York City, vice-president. The former was elected to serve on the Board of Control for one year and the latter for two years. A. S. Bedell, State Department of Health, Albany, was reappointed secretary-treasurer.

At the morning session Lawrence Luther gave a paper describing construction and operation of the sewerage system and sewage treatment works at Freeport, Long Island.

At the luncheon, Dr. Huntington Williams, Secretary of the State Department of Health, welcomed the group on behalf of Dr. Parran, the State Commissioner of Health, and assured them of the latter's interest in the activities of the Association. W. J. Orchard, as usual, supplemented his delightful humor with a serious appeal to make use of civic pride to obtain sanitary improvements through some system of scoring health standards.

The afternoon was devoted to a symposium on sludge, Mr. E. F. O'Brien of Syracuse, N. Y., opening the discussion on "Collection and Digestion," followed by a prepared discussion by W. B. Corwin, Larchmont, N. Y. Mr. W. A. Ryan, Rochester, N. Y., presented a paper on "Drying and Disposal," which was followed by a prepared discussion by Morris Cohn, Schenectady, N. Y., and G. E. Willcomb, Albany, N. Y. Both subjects were fully discussed from the floor.

The next meeting of the Association will be held in Freeport, N. Y., on June 5–6, 1931.

A. S. BEDELL, *Secretary*

Florida Short Course in Water and Sewage Treatment

West Palm Beach, Florida

March 31–April 3, 1931

The second short course for waterworks men was held this year in conjunction with the Florida section of the American Water Works Association.

The short course was devoted solely to the needs of filter plant operators. Papers were presented by H. W. Streeter of the U. S. Public Health Service; A. S. Behrman of the International Filter Co., Chicago; David G. Thompson, U. S. Geological Survey; H. E. Beckwith, Pitometer Co., Harrisburg; and Paul Hansen, Pearse, Greeley and Hansen, Chicago.

Other papers presented were on ground water supplies, filtration plant practices, the ammonia-chlorine process, activated carbons, public relations, sanitary rating of water supplies, financing water main extensions, water supply reservations and waste water surveys.

Texas Water and Sewage Works Short School Thirteenth Annual Meeting

Waco, Texas

January 20–23, 1931

V. M. Ehlers, at the Waco session of the Short Course Water School, made a verbal report in which he recounted some of the outstanding accomplishments in the waterworks field for the past year, and reviewed the manner in which the Texas Section has coöperated with allied agencies in certain activities. He brought out particularly the following points:

The Texas Section was represented by some of its officers at the meeting of the American Water Works Association in St. Louis; at the American

Public Health Association in Fort Worth and Mexico City; and the Texas Pool and Beach Association in Austin during the past year.

Members of the Texas Section assisted the Texas State Department of Health in providing ortho-tolidine testing sets for water plant operators in Texas; in a study of underground waters in the State; in the elimination of cross connections in a number of cities; and in a one-day water school held at Longview, which was attended by some twenty interested city officials.

A questionnaire survey of the states revealed the fact that sixteen states are now using the annual short school as a means of training water and sewage plant operators, as well as sanitary inspectors, and mosquito control men.

Interest manifested by the Sewage Section of the Texas Section, S. W. W. A., is exemplified by the fact that there are now 44 Texas subscribers to the SEWAGE WORKS JOURNAL, a magazine published four times a year, at a special price of $1.00 per year instead of the regular price of $3.00, the arrangement being made possible by a special agreement with the Federation of Sewage Works Associations.

Attention was called to the last biennial report of the Texas State Department of Health, which includes tabulated data on typhoid fever epidemics occurring in Texas for the period of September 1, 1928, to September 1, 1930. It is interesting to note that water-borne typhoid is gradually fading out in the Texas cities, while in no instance was an epidemic traced to a municipally owned water supply.

Expansion in fields in which the members are interested was pointed out in several particulars.

Interest of the East Texas Chamber of Commerce has been gained in the feasibility of manufacturing lime and chlorine in Texas.

The Engineering Experiment Station at Texas A. & M. College has been requested to conduct experiments on the merits or demerits of concrete pipe and vitrified clay pipe subjected to the varying conditions which obtain in Texas, and to make a report on the findings upon completion of the tests.

The application of ammonia and chlorine (chloramine) for the removal of tastes in water is being tried with fair success at Wichita Falls, Llano, Dallas, Austin, Henderson, Waco and San Benito.

The need of extending the protection of water supplies to the rural districts of Texas was also brought to the attention of the members. The President was asked to take under consideration the creation of a Committee on Rural Water Supplies, which might study the situation and outline a procedure for the future.

V. M. EHLERS, *Secretary*

Reviews and Abstracts

H. W. STREETER

Recent Methods of Sewage Treatment

By Brevet Lt.-Col. William Butler, M.B., D.P.H.

Journal Royal Sanitary Institute, **51**, 541–559 (April, 1931)

Abstracted by F. W. Mohlman

The Main Drainage Committee of the London County Council has been conducting extensive experiments on the treatment of London sewage by bio-aeration methods. The tests have been made at the southern outfall, under the direction of the author, in collaboration with Mr. J. H. Coste, Chemist to the Council, and Mr. J. W. H. Biggs, Chemist, in charge of the laboratories of the northern and southern sewer outfalls.

Sewage is "a mechanical mixture of suspended matters in a liquid medium." Settling is considered to be an elementary form of treatment, but wasteful of the manurial value of the settled solids, if dumped at sea. Digestion of sludge is gaining favor, but (according to the author) disposal of sludge is considered to be a minor part of the main problem of sewage treatment. The treatment of clarified liquor is stated to be the main difficulty of sewage treatment.

The complete treatment of settled sewage by bio-aeration requires oxygen plus active humus, known as activated sludge. Effluents are not completely stable but subject to further decomposition into humus. An activated-sludge effluent, however, should not produce nuisance in "an ordinary unpolluted stream."

Various biological processes were considered for investigation, but these were finally narrowed down to two alternative applications of "the admixture of free humus with sewage," with aeration (1) by diffused air through porous tiles, and (2) by propulsion along shallow channels. Raw and settled sewage from an estimated population of 2000 was treated. The maximum capacities were as follows, in Imperial gallons per 24 hours:

	Diffusers	Channels	Aeration Channels Reaeration Diffusers
Raw	56,000	80,000	.....
Settled	80,000	120,000	300,000

(*Abstractor's Note:* Aeration periods, air consumption and analyses not given.)

If sufficient reaeration is provided, it should be possible to sustain the maximum rate in the treatment channels. The channels used were 60 feet long and two-story, designed by Mr. E. H. Tabor, Asst. Chief Engineer to the Council. The lower channel was smaller than the upper, thus increasing the velocity of flow. It was found to be desirable to admit air to the lower channel near the commencement of the return flow. By suitable fillets at each end of the lower channel, air was trapped under pressure equal to the head of water in the upper channel. This was considered to be an advantage.

An aeration period of one hour or less produced inoffensive stable effluents of a character satisfactory for disposal.

When a large-scale plant was contemplated, some doubt arose concerning the advisability of building long under-and-over channels, due to possible adverse conditions in a dark, inaccessible lower chamber. A new type of channel, with ports of interchange between the upper and lower channels, yielded materially better results. With a supplemental air supply, the superiority of the new over the old channels was represented by an improvement of from 20 to 50 per cent in the quality of the effluent; with no air supply, the improvement varied from 8 to 18 per cent.

A discussion of the paper followed.

Mr. F. R. O'Shaughnessy of Birmingham took issue with the statements that sewage is a mechanical mixture and that separation of suspended matters by sedimentation is an elementary form of treatment. He also believed that, contrary to the author's statement, the disposal of sludge is the most difficult part of sewage disposal. He would like to see the results of an experiment reported by the author, in which it was stated that mere shaking for several minutes of a settled effluent with activated sludge, followed by separation of the sludge, resulted in an inoffensive effluent, stable at 80° C. for several days.

Dr. H. T. Calvert, of the Ministry of Health, paid a tribute to Col. Butler's enthusiasm, and was pleased to note an indication that the London County Council was disposed to contribute toward the maintenance of the purity of the river Thames. He expressed the hope that the author would give, in a subsequent lecture, more detailed information concerning the capacities of the experimental plant, since the inferred comparison of diffuser plant and paddle plant was apt to be misleading.

Mr. H. C. Whitehead, Engineer of the Birmingham Drainage Board, expressed the hope that Col. Butler would furnish records of the experiments and analyses of the sewage and effluent. Partial purification had gone beyond the experimental stage at Birmingham, where a plant was now treating 12 million Imperial gallons per day, reducing the oxygen consumed from 120 to 90 parts per million and removing from 120 to 160 parts per million suspended matter. The power consumption averaged

10.25 horsepower per million gallons. The cost of the plant was $195,000, plus $97,000 for remodeling existing tanks. He would like to know if Col. Butler expected, as a result of his investigations, to reduce the estimated cost of the projected London demonstration plant below $1,220,000 for a capacity of from 5 to 10 million gallons per day.

Mr. Arthur J. Martin, of Westminster, stated that the purifying power of the Thames was overtaxed and that the present settling tanks should be supplemented by partial biological treatment. Complete activated-sludge treatment is probably unnecessary; therefore the London County Council objective need be only partial treatment, or bio-aeration.

Mr. S. Duxbury, of Bedford, and Mr. P. G. Lloyd, of Kingston-upon-Thames, stated that the paper would have been more useful had it contained analyses and operating results.

Mr. J. H. Coste, the chemist who had collaborated with Col. Butler, referred to colloids in sewage and the possibility that electrical forces inherent in the activated sludge might be responsible, to some extent, for removal of colloids. He appreciated the "Gallic clarity of the paper, which might have been obscured if the numerical data desired by some speakers had broken its continuity."

Col. Butler, in reply, stated that it was still his belief that the main problem in sewage treatment is the production of an effluent that will not deaerate the water of the stream into which it is discharged. He assured Dr. Calvert that the conclusions stated in the paper were based upon extensive records, and that units of capacity, analyses of sewage and other data were reduced to a common measure of comparison. In reply to Mr. Whitehead's inquiry regarding cost, he stated that, where a double channel could be used, twice the volume of sewage could be treated on the same area, which represented a demonstrable direct saving.

In conclusion, he said that he had attempted to give only a connected account of the main happenings and aims of the tests, although the engineer or the chemist or the sewage works manager might desire to be furnished with data of more immediate practical value.

The Berlin-Stahnsdorf Sewage Treatment Works

BY F. LANGBEIN

Zeits. des Vereins Deutscher Ingenieure, **74**, 1349 (September, 1930)

ABSTRACTED BY G. P. EDWARDS

Berlin has at its disposal more than 27,170 acres for sewage farms which treat sewage at the rate of about 6400 gallons per acre per day. If the lighter, more favorable daily load of 4800 gallons per acre is used, then an

additional 8645 acres must be made available. It is estimated that 71,630 acres will be necessary in 1955. If the relationship between natural land and sewage farm land should hold correct, then the acreage in 1955 must be increased to 214,890 acres of which only one-third could be used for sewage. The high cost of land and the inefficiency of sewage farming led the City of Berlin to the plan of building several large treatment plants for the purification of increasing amounts of sewage.

The first large treatment plant, with a daily capacity of 24,000,000 to 48,000,000 gallons, is under construction south of the city, in Stahnsdorf. Half of the preliminary purified sewage will flow to the sewage farms and the other half to the activated-sludge tanks. The plant consists of preliminary settling tanks, preliminary sludge-digestion tanks, sludge heating apparatus, digestion tanks, machinery house, aeration tanks and secondary settling tanks. Fish ponds and sludge-drying beds are also provided for. The screenings will be burned. The fresh sludge from the settling tanks, to which the excess activated sludge is added, will be pumped once daily to the preliminary digestion tanks. It then flows through the heaters to the digestion tanks. The gas is purified and collected in a gas tank.

Since both purification processes are in operation side by side, their actions can be easily compared. The value of settled sludge and of activated-sludge effluent for agricultural purposes should be investigated. Although two-story tanks are used at the Wassmannsdorf treatment plant, separate settling and digestion tanks are being built at Stahnsdorf. Grit chambers, preliminary settling and secondary settling tanks are divided into two groups, the design of each being basically different. Four aeration tanks will be operated only for experimental purposes. Power requirements for machinery, heating and illumination will be obtained from the digestion gases, which will amount to about 350,000 cubic feet per day. An electrical generator will be operated by two gas engines.

About 300,000 cubic yards of earth were excavated, and about 73,000 cubic yards of concrete, with 6000 tons of iron, were used in construction.

The Treatment of Sewage by Means of Activated Sludge

BY DR.-ING. EDGAR WINTER

Monograph 9, *Gesundheits-Ingenieur*, Munich (1931)

REVIEWED BY F. W. MOHLMAN

This monograph deals with the theory and operation of the activated-sludge process, with specific reference to results of experimental work at Waldenburg. Reference is made to English types of plants but American

progress is almost completely ignored. The monograph as a whole seems somewhat elementary. It comprises primarily a review of the literature, with a rather logical and clear presentation of the various types of plants.

A short reference to the development of activated sludge includes mention of an experiment by Dunbar, in 1904, in which he mixed films from a biological filter with sewage and, after shaking for some time, determined that the sewage was completely purified.

The mechanism of the action of activated sludge is primarily clarification by adsorption, with re-activation of the sludge floc by biological action. It is desirable to remove the coarser suspended matter by preliminary sedimentation. The excess activated sludge can be returned to the raw sewage and allowed to settle in the preliminary tanks. The intimate mixing of fresh and activated solids is desirable for proper digestion.

Diffused-air methods of aeration are: (1) the original type of ridge-and-furrow construction, (2) the spiral-flow aeration scheme developed by Hurd and (3) the Kremer scheme of aeration, or circulation, induced by air-lift action from the bottom of various hoppers, with air introduced 20 to 36 inches below the surface.

The air required by sewage of various concentrations was estimated by Eddy in 1922 to vary from 1.0 to 6.0 cubic feet per gallon. With the Hurd type at Indianapolis, the air consumption is 0.5 cubic foot per gallon (? *Reviewer*). The air consumption decreases with an increasing aeration period, thus with 8 hours aeration only half as much air is required as with 4 hours aeration (? *Reviewer*).

Mechanical methods of aeration include: (1) the Simplex aerator, (2) the Hartley paddles and (3) the Haworth paddles. The power required for each of these is, respectively, 25, 17 and 8 horsepower per million gallons. The combination of paddle wheels and diffused air, as used at Essen-Rellinghausen, requires 7 horsepower per million gallons. (*Reviewer*. No data or references are given to substantiate these statements.)

The operation of an experimental Haworth plant at Waldenburg demonstrated that phenol wastes could be treated in amounts up to 10 per cent of the sewage flow. Experiments on the reaeration of sludge by diffused air indicated that 1 cubic foot per gallon would be required.

Settling of activated sludge was studied. It was found that more rapid settling occurred in inclined than in vertical cylinders. (*Reviewer*. The diagrams were taken, without acknowledgment, from the Second Report of the Investigation of Stockyards Waste, The Sanitary District of Chicago, p. 140, 1922.) Various types of hopper-bottomed settling tanks are described, but no mention is made of final settling tanks with mechanical means for sludge removal, as used almost exclusively in the United States.

Returned sludge must be aerated to restore its adsorptive effect. Kolkwitz in 1926 observed that when growths of filamentous organisms, such

as *sphaerotilus fluitans*, are present the filaments act somewhat as the ribs of an opened umbrella in collecting watery solids, giving rise to "bulking." Reaeration improves this condition.

Settled sludge from preliminary tanks preceding aeration tanks should be disposed of by digestion. Freshly settled solids are reduced from 95 per cent to 80 per cent moisture by digestion. Excess activated sludge should also be disposed of by digestion. The amount of this will vary according to the degree of preliminary treatment. Elrod claimed there was no excess sludge in his plants in Texas due to a high degree of preliminary clarification. (*Reviewer*. This is hardly representative of American experience.)

The digestion of excess activated sludge at Essen-Rellinghausen, according to Sierp, reduces its water content by 80 per cent; gas production is 16 liters per capita per day; sludge digestion capacity should be 1.8 cubic feet per capita.

The activated-sludge process will treat a larger volume of sewage per unit area than any other process now in use. Cost data are available from the Essen-Rellinghausen plant in Germany. The cost of operation of an activated-sludge plant is estimated to be double that of a trickling-filter, but the construction cost of the latter is considerably greater, so that the total costs of operation, including interest and amortization, appear to be about the same for both processes.

The Influence of Chlorine on an Activated-Sludge Plant

BY H. D. BELL

The Surveyor, **79**, 217–218 (Feb. 6, 1931)

ABSTRACTED BY E. HURWITZ

During 1929 and 1930, experiments carried on at the Barnsley plant demonstrated that chlorine was effective in reducing the load on the bio-aeration unit, through a period of abnormally high temperatures and drought. On the strength of these experiments, it was decided to install a permanent plant, using chloride of lime as the source of chlorine. One of the difficulties encountered was the lack of a suitable diluting liquid for the preparation of the chlorinating liquor. It was not deemed advisable to use the tank effluent, which had been used in the 1929 and 1930 experiments, because of its high chlorine-absorption power. The problem was finally solved by using the water from an abandoned shaft and placing the suction line in such a position that the final effluent could be used as an alternative, should the shaft supply fail. The rest of the chlorinating unit consisted of an iron mixing tank divided into two units of 1000-gallon

capacity and fitted with suitable outlets for liquid and for sludge, if necessary. The total cost of the unit was about $250. Its capacity could be varied from 25 to 250 gallons per hour, and the available chlorine in the liquor could be adjusted from 0.05 to 0.6 per cent, as required. The unit has proved ample for the distribution of chlorine to as much as 750,000 gallons of sewage per day.

The bio-aeration unit, originally designed for 500,000 gallons per day, has, with the aid of chlorine, successfully treated an average of 764,400 gallons from April, 1930, to January, 1931. The average chlorine dosage over this period was 10.46 parts per million. The per cent purification based on the four-hour oxygen absorption was 90.8 per cent; the reduction of albuminoid nitrogen was 91.1 per cent; suspended matter in final effluent, 12 parts per million; and the number of putrefactive final effluent samples, none out of 207 determinations.

The Rôle of Protozoa in Activated Sludge

BY ROBERT CRAMER

Ind. and Eng. Chemistry, **23**, 309–313 (March, 1931)

ABSTRACTED BY F. W. MOHLMAN

Experiments have been run at Milwaukee in an attempt to furnish an adequate theoretical explanation of the activated-sludge process. It was proved some years ago by Dr. John Arthur Wilson that oxygen is necessary. Dr. Wilson's work on the mechanism of the process has often been falsely interpreted as meaning that clarification by activated sludge is a purely chemical process. The present experiments prove that protozoa are necessary in the process of clarification, and that bacteria, both aerobic and anaerobic, decompose organic matter and leave it in a colloidal state, in which it will not settle but will remain dispersed.

The research laboratory of the Milwaukee Sewerage Commission took up the study of the fundamental character of the activated-sludge process toward the end of 1929. It was difficult to run laboratory aeration experiments, consequently oxygen was supplied in the form of sodium chlorate. The addition of 0.05 per cent sodium chlorate to raw sewage prevented it from becoming septic. With 0.3 per cent, the sewage clarified in from 2 to 4 days and a typical sludge was formed, "which could in no way be distinguished from activated sludge." Most of the experiments were made with 100 cubic centimeter samples, in small glass containers about 5 centimeters in diameter. Conclusions were made on the basis of whether the sewage appeared to be clear, or became septic. Statements of results appear as "becomes septic," "does not clarify or become septic,"

"clarifies in 10 days," and "does not putrefy." Analyses of sewage and effluents are not given.

If the sewage was first sterilized, either by heating it in an autoclave at 15 pounds for 28 minutes, or with chloroform, addition of sodium chlorate did not produce clarification. Addition of one drop of activated-sludge suspension to the heat-sterilized sewage "caused it to become septic." Addition of 0.3 per cent sodium chlorate and one drop of activated-sludge suspension "caused clarification." The addition of raw sewage or plant effluent, instead of activated sludge, produced the same result.

Enzymes, supposedly obtained by filtering activated-sludge liquor or plant effluent through a Berkefeld filter, "produced no clarification" in sewage to which chlorate had been added and to which air had access. Sewage bacteria and yeasts, taken from an agar slant, were introduced into heat-sterilized sewage containing 0.3 per cent sodium chlorate. "The sewage neither clarified nor did it become septic." Addition of 1 cubic centimeter of raw sewage "caused it to clarify."

When activated sludge was heated to 60° C. for 30 minutes, it was considered that all protozoa were killed, but not bacteria. Inoculation with this sludge did not produce clarification in sterile sewage containing 0.3 per cent sodium chlorate, but further addition of a drop of water containing a single protozoan "produced clarification in 1 week." Further inoculation, with this sludge, of sewage containing bacteria and yeasts produced clarification in 48 hours or less.

Algae were found in the sewage and sludge. In one experiment, 50 parts per million copper sulphate was added to kill the algae. Addition of 0.3 per cent sodium chlorate and access of air to the surface produced clarification.

It was assumed that one type of protozoa, vorticella, could be produced in pure culture by heating sludge at 50° C. for 5 minutes. The vorticella could not be freed from bacteria. Vorticella and paramecia were identified most readily. The former organisms were found anchored to a sludge particle by a coiled stem. No still picture can convey an adequate idea of their activity, "and their energetic, apparently purposeful movements." When they were paralyzed with osmic acid, they soon decomposed and live bacteria seemed to leave their bodies (although this observation was not definitely confirmed).

The experiments indicate to the author that protozoa are the effective agents in the action of activated sludge and that "the maintenance of a quantity of reserve sludge in the best of biological condition, to be introduced into the plant either in small doses regularly or in a large dose when needed in an emergency, may well be made a feature in new plant design and operating schedules."

Previous studies by Dr. Wilson and the author indicated that, other conditions being equal, the aeration time required for effective clarification

varied in inverse proportion to the amount of solid matter in suspension in the mixed liquor. This observation is confirmed by the present experiments from a new point of view. "A given quantity of dispersed organic matter (in the raw sewage) will be converted by a greater number of organisms in a shorter time, if in both cases they are equally vigorous."

The Movement of Liquid between the Settling and the Digestion Compartments of Two-Story Tanks

BY DR.-ING. WILHELM REINHART

Monograph 10, *Gesundheits-Ingenieur*, Munich (1930)

ABSTRACTED BY G. P. EDWARDS

In order to obtain information concerning the internal processes of settling tanks, such as the motion of liquid between the settling and the digestion compartments of two-story tanks, series of tests were made in a glass experimental tank. This tank was about 21 inches long, 12 inches wide and 13 inches deep, and had a capacity of about 13 gallons. In general design, the relative dimensions of the tank were kept to the same scale as those used in practice.

There is generally a flow of liquid in the digestion compartment as well as in the settling tank, when tanks have open slots between their upper and lower compartments. It is theoretically, as well as practically, impossible to prevent liquor passing from the settling to the digestion compartment in such tanks. If the sludge liquor is dense enough the liquor movement in the digestion tank is confined to the upper layers, provided temperature conditions are favorable and the tank is properly built. However, if the rate of flow in the settling compartment is too great or if the tanks are not properly constructed, fresh sewage may flow through both compartments.

When fresh sewage enters the digestion tank, some sludge liquor is displaced into the settling chamber. The smaller the amount and the slower the speed of the fresh liquor entering the digestion chamber, the smaller the exchange. This exchange from hydrodynamic mixing, assuming normal temperature conditions, is mainly dependent on the type of construction, the concentration of solids in the sludge liquor and the rate of flow of the liquid. This has been calculated to be 0.1–0.4 per cent of the sewage flow in a well-constructed plant. Other factors may bring this value to 0.5–0.66 per cent.

This small exchange of liquor is quite harmless. It is important that the rate of flow through the settling tank be small enough so as not to cause a large flow through the digestion tank and large enough to prevent the sewage from becoming septic.

Although systems such as OMS tanks with submerged settling tanks were not investigated, the results obtained indicated that, in such tanks, the exchange of liquid would be greater and the washing-out process more rapid than in the Imhoff type.

A small flow through the digestion tank is desirable as it increases bacterial activity. The tests have shown that practically all of the flow occurs in the section of the digestion chamber open to the settling tank. In Imhoff tanks, the section behind the baffle is quiet. This can be remedied by using the Munich or Dywidag type of tank or by using an Imhoff tank with symmetrical baffles. However, the floating cover space may be too small and the slots are easily clogged in this type of Imhoff tank.

The best construction has, at the effluent end, an overflow weir with a baffle in front of it. At the influent end, a sloping trapezium-shaped false wall in connection with a baffle is very efficient. The ratio between the immersed surface of the false wall and the cross-section surface of the settling chamber should be about 1 to 7. The immersion depth should not be too great and the lower edge of the false wall should not lie below the bottom of the influent channel. The ratio of the immersion depth of the false wall to the depth of the slot can be between $^1/_4$ and $^1/_5$.

The distance of the false wall from the influent wall is extremely important. The distance is not directly proportional to the length of the settling chamber but should be from 10 feet to 11 feet 9 inches. The slope of the false wall toward the influent wall should be about 15°. These dimensions and proportions apply only to tanks of the Imhoff type, with a flow of 8.5 to 42 inches per minute, along the long axis of the settling chamber.

Treatment plants for homes are different from municipal plants in that they are much smaller and have an intermittent flow. Both factors are disadvantageous to the smaller plant and are causes for poorer results. Generally such plants have too small a settling tank and are poorly designed. Sudden heavy intermittent loads upset the action in the digestion tank. In general small domestic treatment plants should be avoided and homes should be connected to municipal sewerage systems.

Recently sludge liquor in two-story tanks has been heated to 20° C. to increase gas production. Temperature investigations have shown that, in order to prevent the digesting sludge from rising, the sludge should not be more than 5° C. warmer than the sewage. The danger of a greater temperature difference exists mostly in autumn and winter when the sewage is cooled by melting snow, while the digestion room is still warm from summer or from warm sewage. It is good practice to measure the temperature of the fresh sewage and the sludge, so as to prevent an overturning of the digestion tank. This danger may be prevented in four ways.

1. Prevent snow from entering the sewer.
2. Cool the digestion room artificially.

3. Artificially raise the concentration of solids in the sludge.
4. Bypass the cooled fresh sewage into the storm water canal.

If the first two methods are not practicable, increased concentration of the sludge can be obtained by the addition of a salt not harmful to bacterial activity. Temperature and concentration experiments indicate that artificially raising the concentration of solids in the sludge liquor removes the danger of a turnover of the digestion tank by unfavorable temperature conditions. It also permits a smaller exchange of liquid between the settling and digestion tanks and indirectly affords a better clarification. Probably the best and cheapest solution of the problem is to bypass the super-cooled fresh sewage into the storm channel. A temporary addition of sewage to a diluting body, in winter, would be harmless from a biological standpoint.

Separate digestion tanks may be heated to increase gas production, whereas this is impossible with Imhoff tanks. The cost of construction for two-story tanks is generally higher than for single-story tanks, because of the greater depth necessary. However, operation and maintenance costs are generally lower for Imhoff tanks. If gas collection is a main issue in the selection of a system, single-story separate digestion tanks are to be preferred to two-story tanks.

The Construction and Operation of the Secondary Digestion Tanks at the Tafelwerder Treatment Plant in Halle

BY PROF. DR.-ING. HEILMANN AND DIPL.-ING. W. MÜLLER

Gesundheits-Ingenieur, **54**, 161 (March 14, 1931)

ABSTRACTED BY G. P. EDWARDS

Investigations have shown that although 353,000 cubic feet of digestion space is necessary at Halle, only 205,000 cubic feet are available. If secondary digestion tanks, heated to 20° or 25° C., are used, this necessary additional space can be reduced from 148,000 cubic feet to 67,000 cubic feet.

In 1929, a heated secondary digestion unit with 35,000 cubic feet capacity was built. This unit consists of two connected round digestion tanks, 36 feet in diameter. The tanks are covered with earth as a protection against cold. The digestion room has a horizontal cross section of about 2430 square feet and an average depth of about 12.7 feet, with a maximum depth of 24.5 feet. There is a gas collection surface of about 700 square feet and the openings to the gas domes are about 27 square feet.

Sludge is drawn from the Imhoff tanks by hydraulic pressure to a sump from where it is pumped by air lift to the secondary digestion tank. Here the sludge flows in an open channel, where it can deaerate and enter the

tank about 12 feet below the sludge surface. The digested sludge is drawn from the bottom of the tank with hydraulic pressure. The tanks are hopper bottomed, with a slope of 1:2. Each tank has a draw-off pipe for scum or sludge liquor, under the gas domes. No liquor could be withdrawn, however, because the space is always filled with scum. Apparatus for circulating the sludge is also provided.

The heating equipment consists of coils of copper pipe, 23 to 26 millimeters in diameter, placed on the hopper bottom about 5 inches off the floor. At every 6 feet the pipe is supported by bricks and fastened with strong copper wire. There are two coils, about 450 feet in length, in each tank. Contrary to American practice, where the heating coils are arranged in parallel rings on the wall of the tank, these coils are placed on the bottom in the form of an Archimedes spiral, in order to obtain equal heating of the sludge. By placing the coil 5 inches from the bottom, the sludge sticking to the pipe can be easily removed.

A motor, which uses digestion gas, drives an air compressor and a hot-water pump, which has a capacity of about 26 gallons per minute. The heater, which also uses digestion gas, has a capacity of about 700 k. calories (2775 B. t. u.) per minute. Hydrogen sulphide is removed from the digestion gas to reduce corrosion of the metal parts.

The gas domes are wrought-iron pyramidal bells which dip about 12 to 20 inches into the sludge liquor. The gas is metered and collected in a large tank.

The temperature of the sludge is measured by two recording thermometers which are placed about 7.5 feet below the surface. The amount of hot water used is measured and the temperature of the water entering and leaving the tank is recorded daily. The amount of gas produced, as well as the amount used in the heater and by the motor, is measured.

At intervals of from 1 to 8 days, 264,000 to 660,000 gallons of sludge are pumped from the Imhoff tank to the secondary digestion tank. The digestion period during the first part of 1930 was comparatively long but later amounted to only 12 to 15 days. This sludge was mainly scum from the Imhoff tanks and contained about 65 per cent organic matter on the dry basis. After the digestion period of from 15 to 30 days, the organic matter decreased to between 50 and 55 per cent. The water content of the digested sludge was about the same as it was initially and amounted to more than 90 per cent. The pH varied from 7.1 to 7.6 during the first week. The digestion tank temperature varied from 21° to 27° C. Circulation of the sludge was tried but no advantage in this procedure could be seen. The formation of scum did not seem to hinder the sludge digestion.

According to the measurements, the heater transferred about 143 k. calories (567 B. t. u.) per cubic foot of gas to the hot water. The heat

given off by the heating coil from a surface of 263.6 square feet was calculated to be 4.5 k. calories (17.8 B. t. u.) per square foot per hour for a difference of 1° C. between the hot water and the sludge. The hot water flows through the coil at a rate of about 1.2 feet per second. In April, the heat transfer for a temperature difference of 1° C. was 3 k. calories (11.9 B. t. u.) per square foot per hour, while only one heater was in operation and the rate of flow of hot water was only 0.6 foot per second. If this value is compared with 50 k. calories (198 B. t. u.) obtained in heating water by coils with a rate of flow of about 1.2 feet per second, it is found that the value for sludge is only about 9 per cent or 4.5 k. calories (17.8 B. t. u.) per square foot per hour, for 1° C. difference in temperature.

The daily heat losses vary between 0 and 11.4 k. calories (45.2 B. t. u.) per cubic foot of digestion space, according to the time of the year and according to the length of time the sludge remains in the digestion tank. With a short digestion period, the heat losses would be almost balanced by the self-heating of the sludge.

The gas produced from a 35,000-cubic-foot tank amounted to from 14,000 to 17,600 cubic feet per day, from January to May; 26,500 cubic feet, from June to September; and 35,300 cubic feet, from October through December. This large increase in gas production is due to a larger quantity of sludge in the digestion tank.

The gas used in heating the secondary tank and by the gas motor was only 6000 cubic feet per day, so that a considerable excess of gas could be delivered to the municipal gas works. From December 1, 1929, to November 30, 1930, 27,534,000 cubic feet of gas was obtained from the entire treatment plant, which was used as follows:

Gas motors for sludge and gas requirements	2,259,000
Gas motor for the storm water tank	459,000
Heating plant for the secondary digestion tanks	2,118,000
Gas delivered to the gas works	22,698,000
TOTAL	27,534,000 cubic feet

About 190,000 inhabitants of Halle contribute to the treatment plant so that the gas produced amounted to 144.7 cubic feet per capita per year, or 0.39 of a cubic foot per capita per day. This amount will doubtless be greater in the coming year, since the secondary digestion tank will operate more efficiently. An average analysis of the gas is as follows:

Methane	69.8 per cent
Carbon dioxide	29.0 per cent
Nitrogen	1.1 per cent
Hydrogen sulphide	0.1 per cent
Heat value	732 B. t. u. per cubic foot

A second separate sludge-digestion tank similar in size and in most other respects to the first unit is under construction. It was observed that in the first separate digestion tank the gas-collection surface was too small, and considerable gas escaped through the slots. To correct this fault, the gas-collection surface in the second tank was made 2430 square feet, or more than three times as large as in the first. The number of gas domes was also increased from four to eight. The openings into the gas domes are about 55 square feet. The greatest depth from the hopper bottom to the upper edge is 26 feet. In the new tank, the cover is supported by the walls of the balancing chamber instead of by columns placed in the digestion room. This construction is simpler and cheaper.

The heating coils are placed 10 inches from the bottom in an Archimedes spiral. The plant is so arranged that thermophilic digestion at 45° C. is possible.

The following are data on the new plant with thermophilic digestion:

Annual amount of sludge	882,500	cubic feet
Lowest temperature of the added sludge	10° C.	
Temperature of the secondary digestion tank	45° C.	
Heat necessary to raise the temperature of the added sludge from 10° to 45° C	3,384	million B. t. u. per year
or	9.5	million B. t. u. per day
Heat losses estimated at	5.6	million B. t. u. per day
Heat requirements	15.1	million B. t. u. per day
or	630,000	B. t. u. per hour

Two boilers, with a capacity of 315,000 B. t. u. per hour each, were chosen for a heating unit.

The heating coils consist of 1800 feet of copper pipe with a diameter of 50 to 54 millimeters and a heating surface of 1076 square feet. The heat transference value was determined to be 17.8 B. t. u. per cubic foot, with a 1° C. difference in temperature and a flow of 1.2 feet per second through the coil. If the rate of flow is doubled in the new plant, a greater heat transference should be obtained. The determined values, however, were used as the basis for calculations. The temperature difference between the hot water and the sludge room is 32° C. The hot water must therefore have an average temperature of 45° + 32° = 77° C. The hot water necessary amounts to about 4750 gallons per hour. The feed water should be about 9° C. warmer than the discharged water.

The sludge and scum will be kept out of the gas domes by wood covers or porous concrete covers. Tap water may be added through nozzles placed below the wooden covers, in order to keep down the scum.

Sludge Digestion as Applied at the Chingford Works

BY W. HUGHES, MANAGER

The Surveyor, 79, 267–68 (February 20, 1931)

ABSTRACTED BY H. GLADYS SWOPE

The four sludge-digestion tanks at Chingford were put in operation in March, 1928. The plant treats sewage from a population of 18,000, and was designed by Mr. A. J. Martin. The digestion tanks are octagonal in plan and are 21 feet deep and 22 feet in diameter. The walls for the upper 10 feet 6 inches are vertical; the hopper bottom is cone-shaped. The total capacity of the tanks is 24,000 cubic feet, but 2400 cubic feet are lost since the head of water in the primary settling tanks is used to discharge the sludge into the digestion tanks. As the inlet to the tanks is 10 feet 6 inches from the top (9 feet below usual working level), the sludge is discharged into the tanks under water. This is a serious handicap, for, if the valve is left open for a few minutes after the sludge is removed, the digestion tanks become overloaded with liquid sewage. The sludge put into the tanks has a moisture content of 94 per cent.

The tanks were originally designed to be worked in series, but difficulties arose. In the first place, Tank 1 was overworked and acid fermentation developed. The second tank gave somewhat better results, but Tank 4 contained mostly water. The latter trouble was due to the placing of raw sludge of density 1.0063 in Tank 1, in which the sludge was in an acid condition, the sludge density being 0.6717. All of the water in the fresh sludge settled to the bottom of the tank and was thereafter withdrawn into the other tanks.

The tanks were therefore used individually and lime was mixed with the in-going sludge. Each day 500 cubic feet of fresh sludge is added to a different tank, thus allowing a lapse of four days before sludge is again added. Mixing is obtained by blowing compressed air through pipes at the bottom of the tank at least once a week. About 350 cubic feet of digested sludge is withdrawn from each tank twice weekly and is run onto drying beds. The digestion period is about 43 days. The digested sludge has a moisture content of 91 per cent. After 4 days on drying beds, it contains 70.5 per cent moisture and, after 10 days, 58.5 per cent. During dry weather the moisture content is reduced to 28 per cent in 14 days.

Two laboratory experiments were run in Winchester quart bottles, on gas production from Chingford sludge. The sludge digested rapidly, digestion being reported as complete in the first test in 42 days and in the second in 14 days. In the first test the initial sludge contained 93.6 per cent water and, on the dry basis, 63 per cent volatile matter. The

digested sludge contained 91.4 per cent water and 45 per cent volatile matter. In the second test 2 liters of sludge gave off 14,300 cubic centimeters of gas. No further data are given.

A Contribution to the Problem of Scum Removal in One- and Two-Story Clarification Tanks

BY J. ZOLLMAN

Gesundheits-Ingenieur, **54**, 61 (1931)

ABSTRACTED BY G. P. EDWARDS

The best method for the removal of scum varies with the kind and composition of the scum as well as with the size of the treatment plant. Oils, fats, corks, pieces of wood, straw, etc., which collect as scum, are generally not easily digested. There has been little reliable information published as to the quantity of scum obtained. Metcalf and Eddy report that, in the United States, domestic sewage contains about 20 parts per million of oil and grease. This fat content is considerably greater than that found in Germany. There are five different methods of scum removal.

(1) Removal by hand is simplest and most suitable, especially for small or medium-sized plants. Since grease decomposes slowly it does not immediately cause the sludge to become septic, and it may be removed in large intermediate tanks. The scum is generally collected in a corner by a movable baffle and skimmed off. This method of removal may be applied to two-story tanks or single-story tanks in which the sludge flows by gravity to sludge sumps, from which it is removed by pressure.

(2) Removal by means of water under pressure was worked out in North America. A pipe, fitted with nozzles having horizontal openings, laid around the edge of the tank, furnishes a stream of water at the surface of the liquid which forces the grease into a corner, where it is easily removed. This system may be used anywhere and is especially economical in medium-sized or large plants.

(3) Removal by means of mechanical apparatus is economical only in plants where the settled sludge is removed mechanically. The type of apparatus depends upon the sludge removal apparatus.

The Link-Belt Company removes settled sludge from long tanks with scrapers fitted on an endless chain which scrape along the bottom. The same scrapers push the scum together on the surface. It can then be removed by hand or automatically over an overflow weir. The Dorr Company skimming apparatus is connected to the rotating sludge scrapers. In addition to these continuous methods, there is the intermittent Leipzig type where the settled sludge is daily scraped into a sludge sump. A

similar movement pushes the scum together at one end and then it is drawn off in a special grease sump. This intermittent method seems to be superior to the continuous ones, although either may be used on flat tanks. During continuous operation, the movement of the water is objectionable.

(4) Removal by compressed air is another method. According to present methods of scum removal, only the oil and grease which float are removed. In the sewer, sand and other solid particles become more or less coated with grease, which makes it difficult to obtain sand free from organic matter in the grit chambers. The grease is also injurious to digestive action, since it tends to hinder digestion and reduces the efficiency of the digestion room. Imhoff aerated the sewage in a special grease trap for several minutes in order to free the mineral matter from its coating of grease and to aid the separation of grease and fat. This method is simple and low in construction cost, has a relatively low operating cost and gives the best practical separation. This process may be used in any type of plant.

(5) Removal by automatic separation is the fifth method to be presented. Due to the difficulties in removing scum in two-story tanks, several types of apparatus, the most typical of which is probably the OMS tank, have the settling tank placed under the surface of the liquid, from which the scum is removed by special slots on top. There are two fundamental errors in this type of construction, especially when it is used with domestic sewage. In the first place, the scum from domestic sewage is composed of difficultly digestible substances, fat, grease and cork. This fat forms a greasy coating on the underside of the cover. If this coating is not removed, it begins to digest and infect the sewage, causing damage to the action in the digestion tank. To remove this coating, it is necessary to partially drain the tank. In the second place, this scum gets into the digestion tank and overloads it. The digestion tank scum, that is, the digesting sludge buoyed up by gas, becomes mixed with the grease and does not settle again. This action may be observed repeatedly in submerged settling tanks.

With a submerged settling tank, the settling section is around the outside of the tank. The center section serves as a part of the digestion tank and as a gas vent. Sludge rising for degassing passes up through the center section and down through the settling section, bringing down the water-soaked greasy scum with it during the circulation. The removal of grease is largely theoretical in submerged settling tanks.

Summary

In small municipal plants, scum (grease and oil) is removed most economically by hand. In medium-sized plants, the removal should be

by hand or by water under pressure, according to local conditions. In large plants, water under pressure or mechanical apparatus should be used. The latter is especially economical when used in connection with mechanical sludge removal.

Metropolitan Drainage Commission of Minneapolis and St. Paul Third Report

1929 and 1930 (157 pages)

BY J. A. CHILDS, CHIEF ENGINEER

ABSTRACTED BY C. C. RUCHHOFT

This report contains additional data and studies that have been made by the commission on the sewage disposal problem of the Twin Cities, Newport and South St. Paul since the 1928 report. (See THIS JOURNAL, I, 657 (October, 1929).)

Studies were continued on the Mississippi River from Minneapolis to Wabasha. Both 1929 and 1930 were low water years. Septic conditions were noted in the pool above the Twin City lock and dam in May of both years. The Hastings dam was completed in the fall of 1930, creating a pool of relatively quiet water 30 miles in length, extending to the Twin City lock and dam. At the Hastings dam the water is discharged against concrete baffles for aeration. Analyses of samples indicated a definite increase in dissolved oxygen in the water.

The analytical data indicated that the river through and below the Twin Cities was nearly as polluted during the summer of 1929 as during the extreme low water in 1926. Even though the discharge in 1929 was nearly twice that of 1926, both the dissolved oxygen and oxygen demand show that the water passing the Twin City lock and dam was nearly as highly polluted during part of the summer of 1929 as in 1926. The bacteriological data substantiated this conclusion. The data collected during the winter of 1929 show the effect of ice coverage upon oxygen depletion in Lake Pepin. The lake water contained over 10 parts per million of dissolved oxygen in December and this steadily decreased as the winter advanced and reached 2.1 parts per million when the ice cover broke up, late in February.

Detailed studies were made of possible intercepting-sewer systems, and a new project was developed which provides for the delivery of all the Minneapolis and St. Paul sewage at Pig's Eye Lake. This site has natural advantages over any other site considered. The Twin Cities could proceed with this project without regard to treatment of the packing-plant wastes

of South St. Paul and Newport and almost eliminate the nuisance now affecting the cities. This project (I-5) provides for the combined treatment of all sewage from both cities, amounting to about 137,000,000 gallons daily, in 1940, and 224,000,000 gallons, in 1970, average dry weather flows in either a trickling-filter or an activated-sludge plant. The intercepting sewer at the treatment works is designed for a maximum flow of 625 million gallons per day for 1970. The construction cost of the interceptors would be about $12,000,000. The estimated construction costs of the treatment works designed on a nuisance-prevention basis are as follows:

	1940	1970
Trickling-filter plant.....	$5,585,000	$13,865,000
Activated-sludge plant.....	3,840,000	8,365,000

The total annual charges of the project, including fixed charges and operation and maintenance for the interceptors, pumping stations and treatment works, for 1940, are estimated as $1,415,000 for a trickling-filter plant and $1,560,000 for an activated-sludge plant.

Ten different methods of apportioning the cost to the two cities were studied. These included straight assessed valuation, straight sewage volume and combinations of these two methods for various portions of the project. The costs to each city by these various methods of apportionment of this project were, in most cases, lower than the costs of independent projects for each city. Two tentative construction programs are suggested. One of these provides for a ten-year period of construction, beginning in 1932, the intercepting sewers to be completed and sufficient for the treatment works installed, so that nuisance would be eliminated by 1942. The second method is a five-year construction program which would provide complete treatment by 1937.

A very thorough study of the inclusion of the wastes from South St. Paul and Newport in the Twin City project was made. These wastes would increase the load on the treatment plant by 22.5 per cent, on the basis of B. O. D., and 16.0 per cent, on the basis of suspended matter. The cost of a separate plant to treat these wastes was estimated to be between $825,000 and $1,300,000 for complete treatment for 1940.

The South St. Paul community alliance proposed to become a part of the Metropolitan Drainage District, if any one of several methods of cost apportionment is used. The most advantageous one of these, to the Twin Cities, is on the straight volume basis. Even this method would probably increase the cost of treatment by 7 per cent, to the cities, on the 1940 program, due to the inclusion of these industrial wastes.

It is still necessary for the cities in this area to obtain the proper authority from the state legislature, in order to proceed with some sewage disposal program.

Experiments on the Destruction of the Filter Fly (*Psychoda*)

BY W. D. SCUDDER AND H. H. GOLDTHORPE

The Surveyor, **79**, 219–220 (Feb. 6, 1931)

ABSTRACTED BY E. HURWITZ

The Huddersfield plant filters are constructed of coarse clinker and are circular in form, with rotating sprinkler distributors. The filters cover ten acres and are from six to seven feet deep. The walls are made of large clinker, held together with wood battens and steel ropes. *Psychoda* have inhabited the filters since their construction in 1910 and, under proper atmospheric conditions, drift over into the neighborhood immediately surrounding the plant. For several years, the principal method of combating them was spraying the walls with creosote and crude oil. Later, it was found that adding an emulsion of creosote to the tank effluent and spraying it over the whole surface by means of the distributors was more effective. In the last two years, however, this method failed to keep the flies under control.

In casting about for other means of eliminating these flies, *o*-dichlorbenzene was tried. Parallel tests in which this chemical and the creosote emulsion were used showed that *o*-dichlor-benzene inhibited the breeding of *Psychoda*, after ten days, and gave immunity from the flies for a month. The creosote emulsion inhibited the breeding after twenty days and gave immunity for a month. In both cases the flies gradually returned until, after two months, they were as numerous as they were at the beginning of the test.

An Innovation in Meat-Packing Waste Treatment

BY H. O. HALVORSEN

Municipal Sanitation, **4**, 166–170 (April, 1931)

ABSTRACTED BY E. HURWITZ

Investigations of methods of treating packing-house waste in such a way that the cost to be borne by the industry should not be excessive, led to the use of chlorine as a precipitant for the large amount of protein present in sewage of this type. It was realized that this nitrogenous material was valuable if it could be economically recovered and its sale would go far toward defraying the cost of waste treatment at the packing plant.

Preliminary laboratory experiments demonstrated that 60 to 90 per cent of the organic material present in the several types of sewage usually found at a plant of this kind, could be removed with chlorine. These experiments also demonstrated that greater recovery, 80 to 90 per cent, was obtained from samples which were fresh and contained only small amounts of protein decomposition products. As a result of these laboratory findings, semi-plant-scale experiments were tried. An average of ten of these runs showed that the sewage would yield about 3 tons of sludge per million gallons, with a nitrogen content of 9.4 per cent, as ammonia.

The experiments were then put on a continuous-flow basis. This demonstrated definitely that at least 3 tons of sludge per million gallons could be expected.

The findings in these preliminary experiments indicated that it was worth while to attempt to treat the entire flow. The sewage was passed through an improvised chlorinator, from which it flowed into a Dorr clarifier. The effluent was discharged into a stream. This treatment removed 70 per cent of the organic nitrogen and 95 per cent of the organic matter. Later it was found that, by eliminating all waste waters not polluted by organic matter, such as condenser water, etc., 80 per cent of the organic matter could be recovered in the form of sludge. This sludge could be dewatered satisfactorily with a suction filter to about 72 per cent moisture and dried in a rotary drier such as that used for ordinary tankage. The dried material had the appearance of tankage and contained 3.70 per cent moisture, 48.90 per cent protein, 9.50 per cent ammonia, 22.72 per cent fat and 11.60 per cent ash. It is hoped that this material can be used as stock feed, which would give it a value of about $30 per ton; or, failing in that, as a fertilizer, which at the present market prices would yield about $20 per ton.

Following these experiments, a permanent installation treating 3/4 million gallons per day was built. The sewage first undergoes a short settling period. It then flows into the chlorinating chamber which has a 20-minute detention period and, from there, into Dorr thickeners. The effluent discharges into a river.

The chlorine is purchased in tank cars and drawn by vacuum to the mixing chamber.

The present cost of operating the plant, including interest, depreciation and upkeep, is about $145 per day. At $20 per ton, the net cost to the packing company would be about $45 per day. If the dried sludge could be used as tankage and sold at $30 per ton, the waste treatment plant would yield a small profit.

The effluent from the plant, which carries a residual of from 0 to 50 parts per million chlorine, has caused marked improvement in the river. No odors are noticeable and the water is clear below the point of discharge.

Some Experiments on the Treatment of a Sewage Containing Wool-Scouring Refuse

BY C. C. BEEDHAM

The Surveyor, **79**, 335-36 (March 13, 1931)

ABSTRACTED BY H. GLADYS SWOPE

Bradford sewage contains large quantities of wool-scouring liquor. The waste is strongly alkaline, yellowish brown in color and often covered with a greasy scum. The composition of the waste varies considerably, analyses for over one hundred samples being:

	Parts per Million		
	Min.	Max.	Avg.
Oxygen absorbed	398	7,400	1,830
Alkalinity to methyl orange	3,430	29,400	6,780
Suspended matter	2,400	30,300	11,520
Grease	3,000	25,800	8,650

After preliminary treatment for grease removal, the waste is generally acid.

To treat adequately a sewage containing wool-scouring wastes, the grease must be removed or destroyed. Grease was separated by sulphuric acid at Bradford. The acid was allowed to trickle into the influent to the precipitation tanks. A constant pH below 4.5 was maintained. For stronger sewages, more acid is necessary and, with crude wool suds, a pH of 2.5 was best for precipitation. Samples of the sewage are titrated every fifteen minutes during the day and night.

The mixing of the acid and sewage was found to be a very important factor. Experiments were run to determine the amount of mixing for optimum conditions. Too much was as detrimental as not enough. Just enough to keep the precipitate intimately mixed with the acidified sewage, and the addition of a small amount of sludge to the mixing tank, was found to give a well-clarified effluent.

Experiments were run to test the efficacy of biological treatment. For trickling filters, the filter medium was "singles" coal, as used at Bradford. Effluent from precipitation tanks was adjusted to a known pH by the addition of acid or alkali, and the liquor settled over night. Supernatant water was then poured off and fed to filters from aspirators. Fifty gallons per cubic yard were delivered to the filters for eight hours, and sixteen hours were allowed for resting. Experiments were run six days each week. For the activated-sludge experiments, the sludge was first formed by aerating crude sewage. These experiments were conducted in cylinders, and a continuous stream of air was maintained in order to keep sludge constantly in circulation. Fifteen per cent by volume was

used to start the experiments and the fill-and-draw method was used. Each working day half the settled effluent (2 hour's sedimentation) was removed and replaced by a gradual addition of the feed. Experiments were conducted during five days of the week.

The percentage purification obtained (based on oxygen consumed from potassium permanganate for 4 hours, at 80° F.) was found to be greatest at a pH of 6. Before biological treatment, then, the mixture would have to be adjusted from a pH of 4 to a pH of 6, by the addition of lime or soda, which would be costly. Fortunately, however, sewage from an out district coming to the works by a separate sewer was very alkaline and contained very little grease. This alkaline sewage was mixed with the wastes treated with acid and the mixture was run into settling tanks. Since this method of working has been adopted, 100 gallons per square yard per day are now being fed to the filters, instead of 70 as formerly.

Modern Treatment and Disposal of Sewage (Especially as Affecting Trade Wastes)

BY T. P. FRANCIS

The Journal of the Institution of Municipal and County Engineers, **57**, 797–829 (Jan. 6, 1931)

ABSTRACTED BY H. GLADYS SWOPE

The author defines sewage treatment as the artificial adaptation of natural processes. In artificial processes the bacterial activity necessary for purification is intensified, therefore purification is more rapid than in the natural process. "The efficiency and economy of biological systems depend on the closeness, frequency and duration of the interfacial contact between their active media and the sewage, on adequate aeration and on the mechanical efficiency developed in the production and maintenance of these conditions."

Trickling filters and activated sludge are both based on biological processes, the difference being in the physical properties of the biologically active media.

Main Principles.—Sewage should be purified so that the effluent, when discharged into a river, will not pollute the river during its dry weather flow in summer. In determining the effective dilution, such conditions as quality and aeration, depth and velocity of flow and proximity of other sources of pollution must be studied.

Domestic Sewage Treatment.—The author discusses two methods of preliminary treatment: (1) screening, grit-chamber treatment and settling-tank treatment, with or without chemical precipitation; and

(2) septic-tank treatment. Except where chemical precipitation is used, there is no reduction in dissolved matter.

For changing the character of the organic material, biological methods must be used—either percolating filters or activated-sludge treatment. Of the latter, there are three main types: (1) Simplex—which is a revolving cone and gives surface aeration; (2) Sheffield—mechanical aeration induced by wave action; the sewage is propelled through continuous concrete channels by paddle wheels; (3) diffused air. The latter can be used in conjunction with mechanical aeration.

Partial purification by activated sludge has been successfully applied, both as an intermediate and as a final process. As an intermediate process when operated in conjunction with percolating filters, it has been found to at least double the capacity of existing filter areas.

In complete purification by mechanical systems the activated sludge to be returned is "reactivated" in the process tanks. This also applies to partial purification by any process.

Mr. Francis defines the purification of sewage and reactivation of the sludge as essentially biochemical processes of oxidation. The greatest demand on dissolved oxygen occurs at the point of contact between the reactivated sludge and the inflowing sewage.

Sludge Treatment.—In England, except for Birmingham and Bath, sludge-digestion tanks are only experimental units.

At Gelsenkirchen, Prüss operates digestion tanks of his own design in conjunction with Imhoff tanks. The Prüss tanks are circular with cone-shaped bottoms. A temperature of 25° C. is maintained by heating the incoming sludge in a calorifier (the sludge passes through tubes surrounded by hot water from a gas boiler). Sludge circulation is secured by an impeller pump.

The Dorr type of digestion tank has a flat bottom and revolving rakes. Heating is secured by hot-water pipes fastened to the circular walls of the tank.

For other types of sludge disposal, such as drying on sand beds and pressing and drying, the author refers to his own article in *Proceedings of the Institution of Municipal and County Engineers*, **56**, 977–99, for a complete study of the subject.

Trade Waste Treatment.—Each type of trade waste requires special study. One of the most important considerations, however, is to have a continuous rather than an intermittent flow of wastes to the treatment plant. Even the sensitive activated-sludge treatment can accustom itself to certain trade wastes, if they are discharged continuously. Any waste containing large quantities of carbohydrate material causes bulking of the activated sludge.

A waste from beet-sugar works and the manufacture of alcohol from

molasses is a serious problem at Stockport and Dagenham. The oxygen-consumed value (4 hours at 27° C.) was 15,350 parts per million and, for the sewage, 127.6 p. p. m. The wastes are decidedly acid and 333.2 grains of lime per gallon would be required for neutralization. Chemical precipitation showed no reduction in dissolved material. Dilution seems to be the only effective means of disposal.

Trend of Developments in Technique.—The conventional type of detritus tank is falling into disuse and is being supplanted by devices employing mechanical means for the removal of grit.

Dorr clarifiers and the Essen-Nord type of settlers are being used preliminary to activated-sludge treatment. In the latter process reaeration tanks are becoming more popular, based on the theory that a long detention period in the reaeration tanks permits shorter time in the aeration tanks.

Chlorination is being used: (1) to keep sewage from becoming septic before reaching the disposal works, (2) to reduce the psychoda on trickling filters and (3) to eliminate surface ponding of filters.

A very interesting and lengthy discussion followed the paper.

Causes of River Pollution

BY F. HEALD

The Surveyor, **79**, 308 (March 6, 1931)

ABSTRACTED BY H. GLADYS SWOPE

The standard established by the Ministry of Health regarding sewage purification was based on a report of the Royal Commission on Sewage Disposal in 1913. In the Salmon and Freshwater Fisheries Act of 1923 a new standard of purity was set up, which should have been acted upon by the Ministry of Health.

Storm water is allowed to reach a river untreated and in many instances this is more of a pollutional factor than trade wastes.

From ten centers above Nottingham, the Trent and its tributaries receive, under normal dry weather conditions, between 70 and 80 million gallons per day of sewage. If this is incompletely treated or if an excess of untreated storm water is added, the risk of serious damage to the river is intensified.

Biological Survey of the River Wharfe

Journal of Ecology, **18**, 274–305 (1930)

ABSTRACTED BY C. C. RUCHHOFT

Introduction: W. H. PEARSALL.—The River Wharfe was selected for detailed study because it represents a northern river which is easily accessible and practically free from pollution. The samples were collected and observations made at three points representing three main stages in the river's course.

I. Dissolved Substances of Biological Interest in the Waters: LABORATORY STAFF OF THE WEST RIDING RIVERS BOARD.—The results obtained during the survey from June, 1926, to November, 1930, are presented. The suspended matter was usually less than 10 parts per million, even at the lowest sampling point on the stream. There are some seasonal variations in the organic nitrogen and oxygen-consumed results. The high results in these determinations corresponded with the occurrence of a brownish color, due to peat. There was very little variation in the biochemical oxygen demands (5 days, at 65° F.) at the upper two sampling points. The B. O. D. at these points was usually about 1.0 part per million, indicating a very clean river. At the lowest sampling point, the B. O. D. varied from 1.1 to 3.3 parts per million. However, on five occasions the results were higher than the corresponding four-hour oxygen-consumed figures, and it was believed that possible pollution was indicated on these occasions. During the entire investigation, the lowest dissolved oxygen saturation recorded was 79.8 per cent.

II. Report on the Invertebrate Fauna: E. PERCIVAL AND H. WHITEHEAD.—Only the invertebrates were studied and of these groups the Protozoa, Nematoda and Rotifera were omitted. The great majority of species found at all stations require water well saturated with oxygen. Representatives of the following groups were obtained in the survey.

1. Aquatic Insect Larvae

   Diptera (Flies), 16 species
   Coleoptera (Beetles), 14 species
   Ephemeroptera (Mayflies), 13 species
   Plecoptera (Stoneflies), 14 species
   Trichoptera (Caddisflies), 29 species
   Neuroptera, 1 species

2. Mollusca, 13 species
3. Hydrocarina (Water Mites), 19 species
4. Crustacae, 4 species
5. Hirudinae (Leeches), 4 species

6. Oligochaeta (Earthworms), 9 species
7. Tricladida (Flatworms), 3 species
8. Hydrozoa, 1 species
9. Porifera (Sponges), 1 species

Tables show the occurrence of the various species at the different sampling points, the stages in the life cycle of the most common forms taken during the various months of the year and analyses of typical samples from various types of river bottoms.

III. Algae Present in the Wharfe Plankton: W. Lawrence Schroeder.—In all of the collections the dominant material was vegetable debris. There were comparatively few filamentous algae and several species were represented by mere fragments. The frequencies given are only approximations, due to the difficulties in statistical enumeration of the minute flora in the presence of debris. Most of the species were limited in their distribution. A table is included giving the various species of Chlorophyceae, Diatoms and Myrophyceae, found during the summer months at the three stations.

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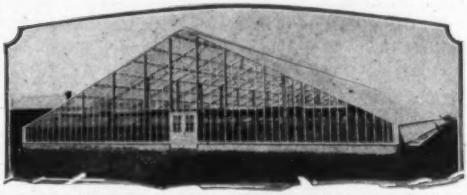

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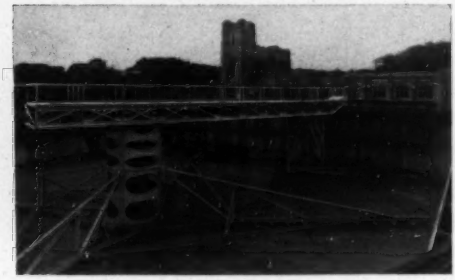

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Statement of the Ownership, Management, Circulation, etc., Required by the Act of Congress of August 24, 1912, of Sewage Works Journal, published quarterly at Easton, Pa., for April, 1, 1931.

State of New York }
County of New York } ss.

Before me, a Notary Public in and for the State and County aforesaid, personally appeared William W. Buffum, who, having been duly sworn according to law, deposes and says that he is the Business Manager of the Sewage Works Journal and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor and business managers are:

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Editor, F. W. Mohlman, 845 South Wabash Avenue, Chicago, Ill.
Managing Editor, F. W. Mohlman, 845 South Wabash Avenue, Chicago, Ill.
Business Manager, William W. Buffum, 654 Madison Avenue, New York, N. Y.
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2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)

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5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the six months preceding the date shown above is: (This information is required from daily publications only.)

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Sworn to and subscribed before me this 24th day of March, 1931.

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Notary Public, Bronx County, Clerk's No. 107.
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(My commission expires March 30, 1932)

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